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TRANSACTIONS

OF THE

AMERICAN SOCIETY

OF

CIVIL ENGINEERS.

(INSTITUTED 1852.)

VOL. LIV.

PART F.

Being the sixth volume of the Publications of the
International Engineering Congress,
held under the auspices of the Society,
St. Louis, Mo., October 3d to 8th, 1904.

Edited by the Secretary, under the direction of the Committee on Publications.

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INTERNATIONAL ENGINEERING CONGRESS, 1904.

Organization and Scope.—The Congress was undertaken, financed and conducted by the American Society of Civil Engineers, at the request of the Louisiana Purchase Exposition. Thirty-seven subjects were selected for consideration, and invitations to contribute papers were issued to specially selected engineers in America and abroad ; each of these papers to be a review of progress during the past decade.

Papers and Discussions.—In response to this invitation ninety-seven such papers were received, nearly all of which were printed in advance form and distributed prior to the Congress for the purpose of eliciting discussion. The nationality of the authors of these papers is as follows :

United States, 51, Holland, 7, Belgium, 1, Russia, 1,
France, 18, Japan, 5, Canada, 1, Switzerland, 1.
England, 10, Austria, 1, Denmark, 1,

One hundred and twenty-four additional written communications have also been received, which, together with the oral discussions at the Congress, after revision by the speakers, form part of this Congress publication.

Meetings.—The Congress was divided into eight Sections: Waterways, Municipal, Railroads, Materials of Construction, Mechanical, Electrical, Military and Naval, and Miscellaneous, and twenty-eight sectional meetings were held. There were also two general meetings of the Congress. The total registered attendance was 876, and the average attendance at each sectional meeting about 50.

Publications.—This Volume is one of six containing the Papers and Discussions of the Congress, published by the Society as Parts A, B, C, D, E, and F, of Vol. LIV of *Transactions.* In these volumes although it has not been possible to retain the subdivision by Sections, and no special grouping of subjects has been attempted, the papers and discussion on each subject are grouped. With each volume there is a table of Contents, and this, which is the last volume, contains an Index covering the entire publication.

Chas. Warren Hunt,
Secretary.

New York, May 16th, 1905.

INTERNATIONAL ENGINEERING CONGRESS.

ST. LOUIS, MO., OCTOBER 3d TO 8th, 1904.

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AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

WHARVES AND PIERS.

Congress Paper No. 75.

OBSERVATIONS ON DOCK WORK IN NEW YORK HARBOR.

By J. A. Bensel, M. Am. Soc. C. E., Engr. in Chief, Dept. of Docks and Ferries, New York City, U. S. A.

Discussion of the Subject by

E. P. Goodrich, New York City, U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 75.

WHARVES AND PIERS.

OBSERVATIONS ON DOCK WORK IN NEW YORK HARBOR.

By J. A. Bensel,* M. Am. Soc. C. E.

The term Dock Construction is applied generally, and particularly abroad, to structures known more specifically as dry docks, graving-docks, floating docks, etc., but in this locality it seems to be applied indiscriminately to what are known elsewhere as piers or wharves. The term is used here to specify the structures at which vessels berth, and discharge and take on passengers and freight.

The main features of construction have varied but little during the growth of the Port of New York; to a great extent the piers are but platforms of a nearly uniform height of about 5 ft. above high water, carrying a superstructure in the shape of a shed for the protection of freight, or bins for the storage of same.

On account of the diversity in cargoes, there may be said to be no development in their mechanical handling either in loading or unloading ships, except in the case of coal, for which very recently special piers have been constructed by the Delaware, Lackawanna and Western Railroad Company, in Hoboken, N. J., which have patented mechanical devices for the loading and unloading of coal in bins, and for the handling of coal cars.

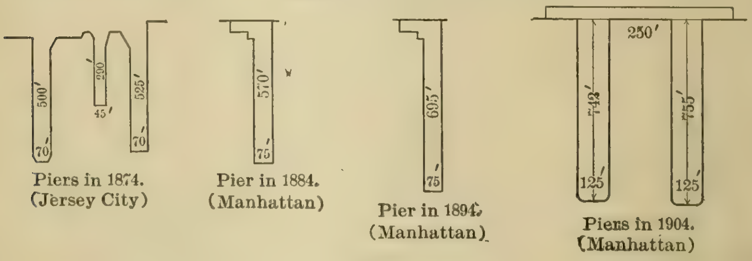
---

* Engineer in Chief, Department of Docks and Ferries, New York City.

The transatlantic lines follow the custom, which has prevailed from early times, of docking and discharging their passengers at individual piers, although, of late years, the common landing-float where passenger vessels stop and discharge passengers before proceeding to their particular berths has developed in Liverpool.

While there has been, as above stated, no particular change in regard to the method of construction of piers at this Port, it is interesting to note the increase in the size of piers and slip space, as well as the variations in the size of ships, which have taken place in the past fifty years.

GROWTH AND DEVELOPMENT OF THE PIERS USED BY THE CUNARD COMPANY, FROM 1874 TO 1904.



Piers in 1874. (Jersey City)

Pier in 1884. (Manhattan)

Pier in 1894. (Manhattan)

Piers in 1904. (Manhattan)

FIG. 1.

Fig. 1 shows the growth and development in the size of the piers used by the Cunard Line, from 1874 to 1904, and may be taken as a fair sample of the growth of the transatlantic docks.

At the present time piers are in contemplation for the use of the Cunard Line more than 800 ft. long and 125 ft. wide.

Plate I, which is taken from a Cunard Line publication, shows the variation in size of the ships of this company from 1840 to the present time. There is no indication at present that transatlantic ships have reached their full development as to size. Changes in

PLATE I. VOL. LIV. PART
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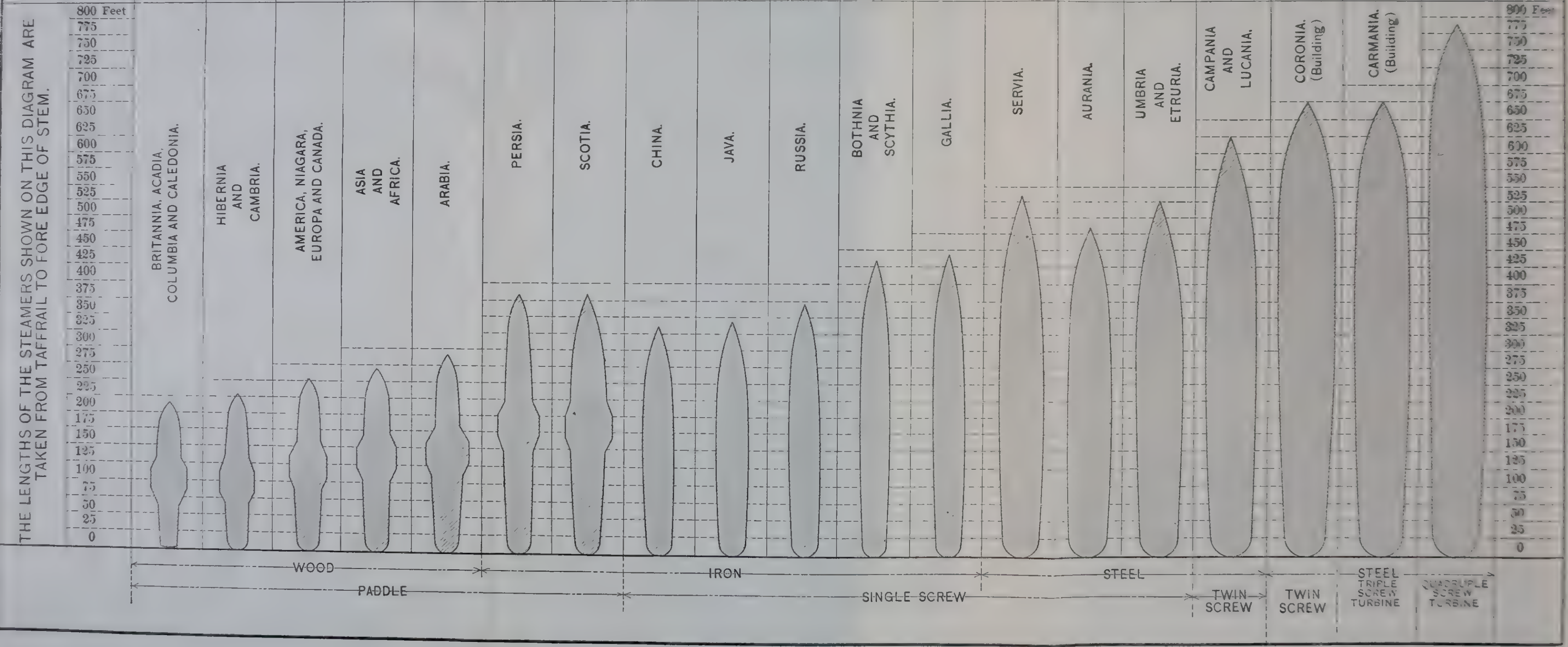
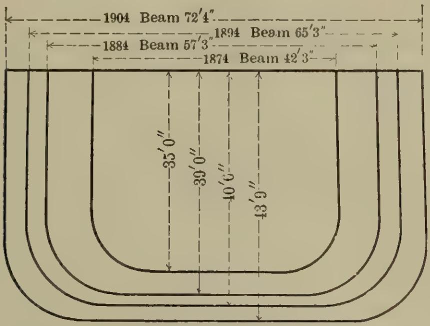
COMPARATIVE SIZE OF VARIOUS TYPES OF CUNARD MAIL STEAMERS FROM 1840 TO 1905.

LENGTH BETWEEN PERP'RS.	207′ 0″	210′0″	251′ 0″	266′0″	285′0″	376′0″	379′0″	326′0″	337′0″	358′0″	420′0″	430′0″	515′0″	470′0″	500′0″	600′0″	650′0″	650′0″		LENG
BREADTH OF BEAM	34′2″	35′9″	35′0″	40′0″	40′8″	45′3″	47′8″	40′5½″	42′6″	42′6″	42′3″	44′3″	52′3″	57′3″	57′3″	65′3″	72′4″	72′4″		BREA
DEPTH OF HOLD	24′4′	24′2″	25′3″	27′2″	27′7″	29′9″	30′5″	27′7″	27′7″	28′0″	35′0″	35′0″	39′9″	37′6″	39′0″	40′6″	43′9″	43′9″		DEPT
GROSS TONNAGE	1139 Tons	1422 Tons	1825 Tons	2226 Tons	2402 Tons	3300 Tons	3871 Tons	2539 Tons	2697 Tons	2959 Tons	4556 Tons	4808 Tons	7391 Tons	7268 Tons	8127 Tons	12500 Tons	21000 Tons	21000 Tons		[illegible]
INDICATED HORSE-POWER	740	1040	2000	2400	3250	4000	4900	2250	2650	3100	3250	5300	9900	9900	14500		21000	21000		I. H. P.
SPEED IN KNOTS PER HOUR	10.4 Knots	11.3 Knots	11.8 Knots	12.5 Knots	13 Knots	13.8 Knots	14.4 Knots	13.9 Knots	14 Knots	14.4 Knots	13.8 Knots	15.5 Knots	16.7 Knots	17 Knots	19.5 Knots	22 Knots			25 Knots	SPEED
DATE	1840	1843	1848	1850	1852	1855	1862	1862	1865	1867	1874	1879	1881	1882	1884	1893	1905	1905		DATE



the method of application of power seem in every case to have been followed by an increase in size, and the application of the steam turbine, in place of the reciprocating engine, now seems to indicate a greater departure from preceding practice than has taken place in some time.

Fig. 2 shows an approximate midship section of the vessels of the Cunard Line at different periods, and indicates the necessity for deepening the channel of the approach to the Harbor of New York, now under way by the United States Government.



COMPARATIVE DIAGRAM OF MID SECTIONS OF CUNARD CO'S STEAMERS BETWEEN 1874 AND 1904.

Vertical heights indicate depth of hull below main deck.

FIG. 2.

The City of New York, which has the greater portion of the water front of the Port, is the only city in the United States that has consistently developed a scheme for municipal ownership, and the control, along municipal lines, of the water front.

In 1870 the then City of New York, now Manhattan Island, began a steady development in the improvement of the water front along the lines of municipal ownership and control. Prior to Consolidation and the creation of Greater New York, in 1898, the total water front, Manhattan Island and the Bronx, amounted to 145 miles. To-day with a water front of between 445 and 604 miles (the first figure being measurement along the shore and the latter around piers), in Greater New York, the City's ownership amounts to 39 miles.

On Manhattan Island, however, the City now owns 20½ miles of water front, 15¼ miles of which is commercially available.

In the acquirement and improvement (divided in the proportion of 2 to 1) of water-front property, the city has expended the sum of $49 776 285.95.

To a great extent the water front along the North and East Rivers and along the Brooklyn shore, admits of the docking of vessels of maximum draft. Harbor conditions are such, however, in the lower bay as to necessitate, at the present time, the arrival and departure of transatlantic vessels of the larger class, at about high water, although within a recent period some Transatlantic ships of less draft have been able to sail on schedule time, independent of the state of the tide. The largest vessels, however, are not only unable to load to their maximum capacity, but must still pass the ship channels at high water only.

The work now under way, on the East Channel, which will probably be completed in a few years, will provide a channel of 40 ft. depth at mean low water.

Tidal observations have been recorded in this harbor by the Dock Department for about twenty years, one of the results of which has been to establish the mean range of tide at 4.24 ft. Extreme variations of about 4 ft. occur above mean high and below mean low water.

Plate II gives graphically the maximum tidal variations in relation to mean low water. In 1898 an examination of the low-water records showed the necessity of raising the mean low-water plane 0.24 ft., and how nearly the present mean low-water line agrees with the observations since 1886, may be seen in the figure.

An inspection of this diagram would lead to the supposition that the relative elevation of the shore and mean water level is changing, this is particularly noticeable in the line showing the elevation above mean low water of the highest tides. Taking this in connection with the fact that the mean low-water level was raised, it might be inferred that the shores of this Port were sinking in relation to the tidal level.

It is probable, however, that mean low water was first deter-

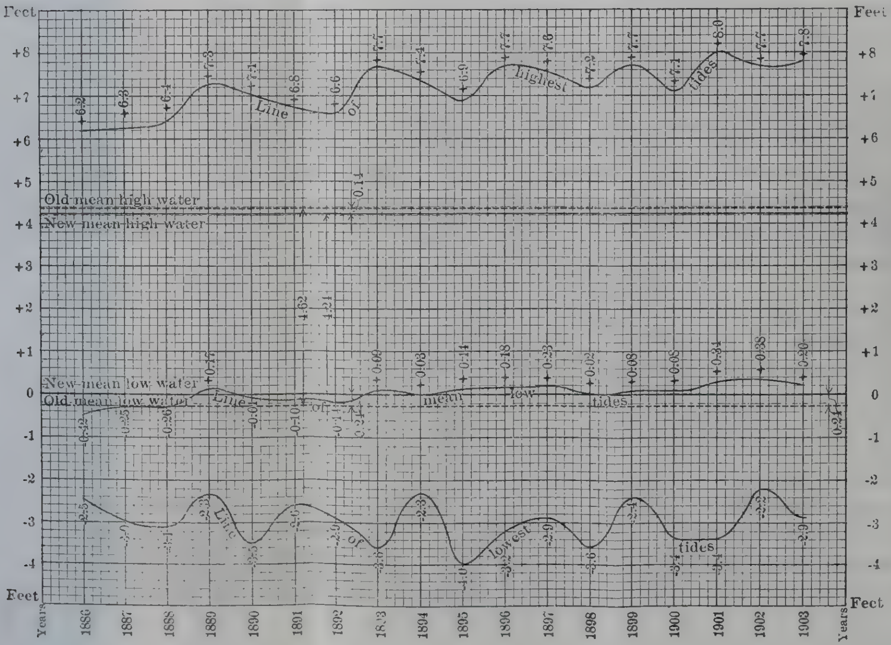
PLATE II. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
BENSEL ON
WHARVES AND PIERS.

AUTOMATIC TIDE GAUGE RECORD.

DEPARTMENT OF DOCKS AND FERRIES, PIER A, NORTH RIVER, NEW YORK CITY.

Diagram showing line of actual highest and lowest tide occurring in each year from 1886 to 1903, inclusive; also the relation of the M. L. tide line for each year to the new M. L. W. plane, and the old M. L. W. plane, as determined by records of automatic tide gauge at Pier A.

Note: In 1886 a plane of M. L. W. (in dotted line) was established after a short running of an automatic tide gauge at Pier A, and this plane remained unchanged until 1898. In 1898 all intervening tidal information from 1886 to 1898, inclusive, was utilized, and owing to the gradual rise of the line of mean low tides as shown, it became necessary to raise the old M. L. W. plane 0.24 ft. higher, thus giving the new M. L. W. plane (solid line). The new line, by reason of its being the average of all the mean low-water records, is well adapted to local conditions. By using all records from 1886 to 1903, inclusive, the low waters approximate the new M. L. W. (solid line) to within 0.042 ft., or, the record for 814 weeks shows the average M. L. W. to be 0.042 ft. above the new M. L. W.



mined with an insufficient number of observations, and that the period of observation is not, as yet, sufficiently long to enable a final conclusion to be drawn in this regard.

The manner of building has varied little during the period of time in which the Port of New York has been in existence. All the piers with few exceptions, notably those built by the Bush Company in South Brooklyn, and two piers at the lower end of Manhattan Island, are pile platforms whose strength and stability depend on piles which act as columns and bear on hard bottom. This is the case with nearly all the piers along the East River, and on the North River south of Canal Street. Along a portion of the North River, however, where most of the transatlantic lines are located, extending from Canal to Thirtieth Street, the hard bottom is at such depth as to make it impracticable to drive the piles to it, and the piers are dependent on the mud friction of the piles for their stability. Although from the penetration of the pile in driving, great sustaining power would not be expected along this section of the water front, loads have been observed as high as 2 000 lb. per sq. ft. of pier, and 45 tons per pile, which is considerably more than calculations give as the ultimate strength of this portion of the structure.

In the Bush Company's piers the nature of the bottom was such as to allow the construction of a solid filled-in pier, the filling being retained by sheet piling placed about 25 ft. in from the pier sides, thus allowing, by sloping the bottom from the sheet piling to the sides of the pier, of a fair depth of water along the sides of the pier with a practical length of sheet piling to retain the filling.

Although as far back as the Stone Age man has used piles for the support of platforms and buildings over water, the carrying power of piles is to a great extent a matter of conjecture, except where determinations are made by experiment.

The writer remembers being particularly struck with the insufficiency of pile-driving formulas when comparing the results of driving piles by the ordinary drop-hammer method and by the steam hammer on a building foundation close to the water front. The satisfaction of an architect in the bearing power of the pile was apparent until by the substitution of a steam hammer the contractor considerably increased the amount of work per day, thereby causing an entire stoppage of the work until an investigation could be made to determine whether underhand methods were not in use which would explain the rapid penetration of piles under the steam hammer.

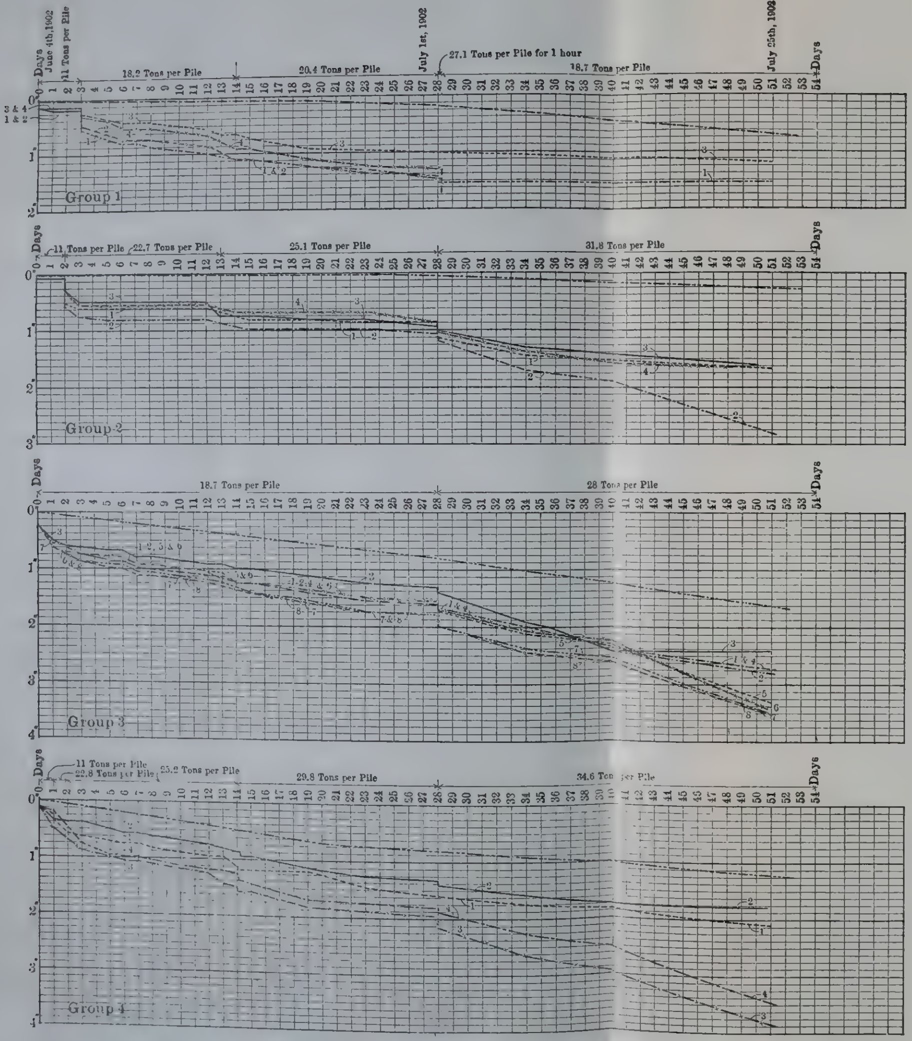
In another foundation for a gas tank close to the water front, piles were driven to refusal with a drop hammer, the driving being exceedingly hard and the number of piles driven per day being small, averaging about five; settlement occurring after the tank was erected, the structure was taken down and another set of piles were driven between the first series, and although from the nature of the first driving the ground was considerably compacted, a steam hammer used on the second set drove longer piles and about three times the number in a day. In the first instance the piles were driven to refusal with a drop hammer. In the second instance with the steam hammer there was no indication of refusal, and the piles were going easily when the driving stopped because the piles were not long enough to be driven further, although they were about 30% longer than those driven in the first instance.

It was deemed advisable to ascertain the actual bearing power of piles in a section of the North River water front now in process of improvement between Bloomfield and Twenty-third Streets, and the results of these experiments are given in Plate III. These experiments were not entirely satisfactory on account of the breaking of the platform before they were entirely completed, but sufficient data were secured to be of value in the particular case in point, and as a check for other work.

It was desired to obtain the relation between the bearing power of piles lagged and unlagged.

With this in view an experimental platform was built near the foot of Seventeenth Street, North River. The piles to be tested were located inside the platform which was so arranged that on the sinking of the test platform the load would be taken up on the piles surrounding it, on the outside or working platform. Four groups of piles numbered as shown in Plates III and IV, were driven, all about 80 ft. long, as follows: Group 1, plain unlagged piles. Group 2, piles lagged with four pieces of 5 by 6-in. lumber, 30 ft. long. Group 3, piles lagged same as in Group 2, but

CURVES SHOWING SETTLEMENT OF EXPERIMENTAL TEST-PILES IN PLATFORMS, CONSTRUCTED FOR DETERMINING THE EFFECT OF LAGGING ON THE PENETRATION AND SUPPORTING POWER OF PILES.



Group No.	Pile No.	Diam. of Point.	Diam. of Butt.	Approximate weight of pile taken at 50 lbs. per 1 cu. ft.	Total number of blows to drive.	Total Penetration in feet into mud.	Sq. feet of surface of pile in mud contact.	Average penetration in inches for each of last 5 blows.	Ultimate bearing power by Trautwine's Formula. (In tons of 2000 lbs.)	Ultimate bearing power by Wellington's Formula. (Tons.)	Load supported for 27 days. (Tons.)	Settlement during 27 days under load stated in preceding column.	Settlement of surrounding working platform in corresponding time.	
1	1	8	18	4200	26	48	139	8	16.1	15.4	18.3	⅛		All piles unlagged
	2	8	17	3900	19	49.6	131	9¼	14.2	13.7	18.7	not taken		
	3	7	14	2700	13	50.9	127	13¼	11.0	9.8	18.7	⅛		
	4	6½	17	3640	11	45.7	123	14¼	9.5	9.1	18.7	not taken		
2	1	6	17	3600	46	49.6	220	4	29.0	27.7	31.8	13/16	5/16	Piles lagged with four 5"x 6" 30'0" long
	2	6½	15	2940	58	50.1	219	3⅝	31.6	30.6	31.8	1 1/16	5/16	
	3	7½	16	3450	46	51.0	233	4	29.0	27.7	31.8	11/16	5/16	
	4	8	16½	3700	60	49.3	238	3	36.3	34.7	31.8	13/16	5/16	
3	1	7	17	3700	70	50.7	247	3⅛	34.6	33.8	28.0	1 1/16	⅛	Do., Do.
	2	8	17½	4060	70	49.8	243	3⅛	34.6	33.8	28.0	1⅛	⅛	
	3	7½	18½	4370	64	49.0	241	3	36.3	34.7	28.0	1⅛	⅛	
	4	9	18	4450	80	49.9	250	2⅝	40.3	38.3	28.0	1 1/16	⅛	
	5	6	22	5700	90	52.6	257	2⅜	42.7	40.7	28.0	1 9/16	⅛	
	6	7½	21	5500	67	49.4	247	2¾	39.2	37.0	28.0	1 11/16	⅛	
	7	5½	22	5060	72	49.7	243	2¾	39.2	37.0	28.0	1⅛	⅛	
	8	9	19	4870	83	48.8	245	2½	41.3	39.6	28.0	1½	⅛	
4	1	5	16½	3270	59	50.7	241	3⅝	31.6	30.0	34.6	⅝	¾	Piles lagged with two 5"x 6" and two 4"x 10" 30 ft. long
	2	10	18½	4870	77	49.4	247	2⅛	41.3	39.6	34.6	⅜	¾	
	3	7½	19	4600	44	47.1	231	4⅜	27.0	25.8	34.6	1 11/16	¾	
	4	7	17½	3890	65	47.8	233	2⅛	37.3	35.8	34.6	1 9/16	¾	

TABULATED RESULTS

Note:-

Vertical Ordinates represent the settlement.

Each division on the horizontal ordinate represents one day.

Curves represent settlement of testing platforms.

Upper curves represent average settlement of working platform around corresponding testing platforms.

Vertical distances between the upper curve and lower curves represent settlement of testing platforms in relation to working platform.

arranged in pairs to obtain the result of a closer spacing, the piles in each pair being spaced 2 ft. 8 in. apart. Group 4, piles lagged with two pieces of 5 by 6-in. lumber, and two pieces of 4 by 10 in., in lengths of 30 ft. to obtain the result of a different style of lagging.

The platforms were loaded with granite and concrete blocks, 18 days after the last pile was driven, which gave the piles a chance to set in the material before they were loaded. The record of the loading and the consequent settlement is fully shown on Plates III and IV.

The piles were under the loads shown in the illustration for about 50 days, and the test was completed when the platforms failed. A boring taken at the site of the platform showed mud of uniform character throughout for a depth of 100 ft. below mean low-water line with a density at the mud line sufficient to allow piles to sink by their own weight from 10 to 15 ft., when lowered gradually. At a depth of 30 ft. below mean low water the mud had the consistency of modeling clay, wet for use. The depth of water about the piles averaged about 22 ft. below mean low water line. The piles were driven by a hammer weighing about 3 300 lb., with a uniform effective fall of about 8 ft. In regard to the bearing power of the piles, it is proper to consider the cause leading to the collapse of the platform. At the time the last observation was taken no lateral movement in the working platform was observed. The test piles were firmly chocked against the test platform and any movement would have been detected. A small lateral movement had been observed in the test piles of Group 3 in a southerly direction and this had been checked by chocking.

The platform failed suddenly, directly after the passage of a large boat in the river, the piles falling in a southerly direction. The last observations taken show the maximum settlement of any test pile to be about 3½ in. and that the settlement of the working platform at the point where this maximum settlement had taken place was about 1¾ in. It should be noted that this latter settlement took place under no load whatever except the weight of the piles and the timber on them, and that therefore the maximum settlement under load of any test pile was practically only 1¾ in. The settlement of 1¾ in. in the working platform was probably due to a gradual sinking of the mud area about the platforms due to the load transmitted by the pile to it. This view is supported by the fact that the greatest settlement in the working platform took place where the greatest load obtained. The total settlement of the working platform at the various groups was as follows: Group 1, $\frac{15}{16}$ in.; Group 2, $\frac{3}{8}$ in.; Group 3 (point of greatest load on test piles), $1\frac{3}{4}$ in.; Group 4 (point of next greatest load on test piles), $1\frac{5}{8}$ in.

A settlement of $1\frac{3}{4}$ in. is not uncommon in pier structures supported on piles of the lengths used in these tests, before the structure is finished and before it has received any other load than its own weight.

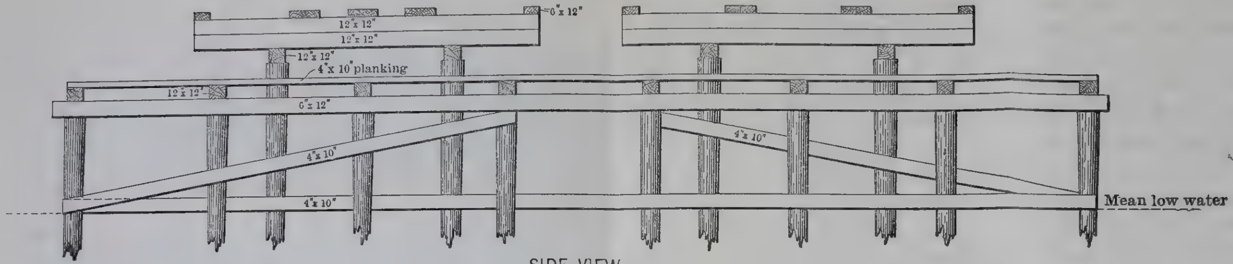
When the last observations were taken there was enough room to allow of a further settlement under the load of 2 in. before the working platform would begin to carry a portion of the load.

The greatest pile load, 34.6 tons, was on the piles of Group 4. Piles 3 and 4 of this group showed a larger settlement and indicated that these would be the piles most likely to go down before any others. If they did the loading on them, 69.2 tons, when distributed over the surrounding piles of the working platform would average about 9 tons per pile. If piles 5, 6, 7 and 8 of Group 3 then settled, their load of 112 tons was distributed over 10 piles, giving an average of 11.2 tons per pile, thus making a total of 19.9 tons on the middle piles of the working platform. This load could only be obtained on the assumption that the lagged piles would not carry more than that amount after they had once begun to settle. As the records show, Group 2, unlagged piles, carried 25 tons per pile for 14 days without any settlement, it is altogether improbable that a load of 20 tons could ever come on the piles of the working platform.

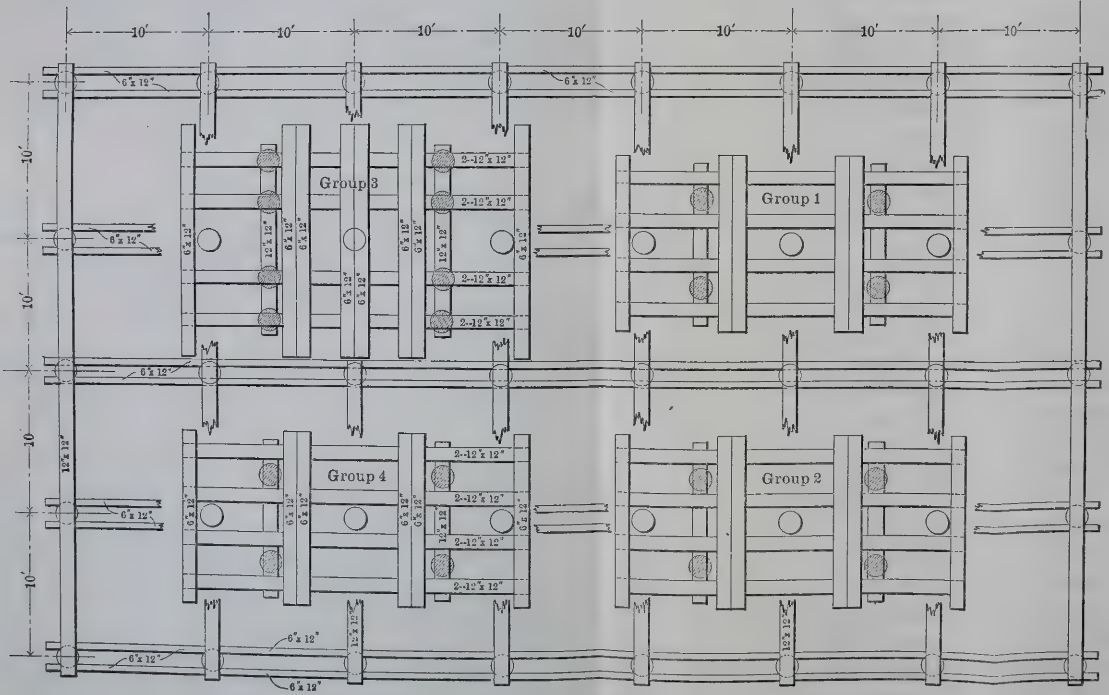
It is concluded that the collapse was caused not by the slipping of the piles through the mud, but by the bending of the piles due to the fact that the working platform did not give sufficient lateral support to the test piles, or that the test piles themselves broke as columns by direct compression. In testing piles it is of course impossible to space them so exactly as to keep them in a vertical position, and it is probable, therefore, that the load acted eccentrically to some of the piles, and that initial stresses were set up in some of the piles before the load was placed.

PLATE IV. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
BENSEL ON
WHARVES AND PIERS.

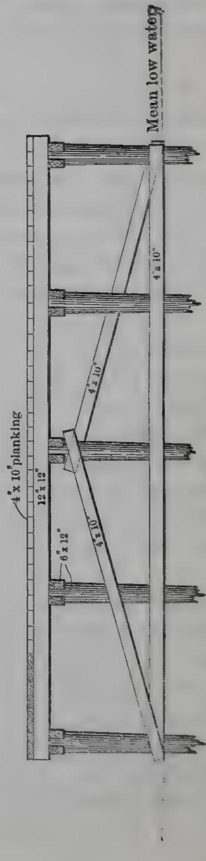
EXPERIMENTAL PLATFORM FOR TESTING EFFICIENCY OF LAGGED PILES.



SIDE VIEW



PLAN



END VIEW

In regard to the bearing power of piles as shown by this experiment, it is to be noted that two of the piles in Group 1 (unlagged piles) showed no settlement under 27 tons, and none of them showed any settlement under 20.5 tons, during a period of 14 days, and, further, that the piles which settled or slipped under 27 tons practically showed no settlement whatsoever under a subsequent loading of 19 tons for 23 days. It seems to be thoroughly safe, therefore, to conclude that the ultimate bearing power of the unlagged piles, under the conditions of the bottom and depth of water shown in this experiment, may be taken at 20 tons per pile, and considering the fact that the piles in Group 2 showed practically no settlement for 14 days under a load of 35 tons, and that Group 4 acted similarly under 29.8 tons per pile, it is concluded that the ultimate mud support of piles lagged in this manner and spaced as shown, may be taken to be at least 30 tons, and that the safe mud support may be assumed as 25 tons.

The lines of settlement in Group 3 plainly show the effect of close spacing, and though the settlement was not marked under 19 tons each, and though no abrupt settlement occurred under 28 tons, piles placed in this manner may be assumed to bear no more than the safe load of 20 tons.

The lines of settlement do not indicate that any of the lagged piles slipped through the mud under the maximum load (the vertical drops recorded of $\frac{1}{8}$ in. to $\frac{3}{16}$ in. are taken to be the compression and bend in the pile), and in these loads the question is reduced to a determination of the bearing power per square foot of the surrounding mud. Inasmuch as the failure of the platform precluded observations over a sufficient period to arrive at such an absolute determination, the practical conclusion deduced is that piles similarly lagged should be treated as columns. With the usual factor of safety, the computed load would be a safe one for a mud support, in the cases observed, with an unsupported length of 55 ft.

A comparison of the results in all of the above tests with the pile formula shows the usual discrepancies due to conditions not in accord with those necessary for agreement.

It was intended to ascertain the penetration of the piles under hammer blow after several months, and thus determine the actual relation between the observed results and those of the formula under fair conditions; but this was prevented by the collapse of the platform. There was no marked difference between the piles driven under this test, whether driven under a 10-ft. or a 15-ft. fall of the hammer.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON
WHARVES AND PIERS.

By Mr. E. P. Goodrich.

E. P. Goodrich, Jun. Am. Soc. C. E., New York City. (By letter.)—New York Harbor, having by far the largest tonnage of any port in the United States, would be expected to have the most diversified system of harbor facilities, although the very facts of the natural advantages which create this tonnage have often served to retard growth, so that along some special lines the harbor does not afford advantages equal to those found elsewhere. Mr. Goodrich.

Of course, no ore piers are to be expected in the Port of New York, one rather looking to the iron and copper districts on the Great Lakes to find the finest constructions. The largest ore dock on the Lakes is Dock No. 2, at West Superior, Wis., and belongs to the Great Northern Railway. Through the courtesy of Mr. A. H. Hogeland, Chief Engineer of that road, the writer is enabled to present, in Plate V, a drawing of this structure. It is 2 100 ft. long, and has 350 pockets, with a total capacity of 87 500 tons of ore.*

Similarly, ore unloading apparatus for vessels is to be found on the Great Lakes almost exclusively.†

In regard to the handling of coal, it has been only during the past few years that really modern devices have been found at New York. The Navy Yard now possesses a modern steel and concrete structure, on a filled pier of the quay-wall construction hereafter

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* *Bulletin No. 44*, American Railway Engineering and Maintenance of Way Association, p. 44.

† "Harbors on Lakes Erie and Ontario," by Dan C. Kingman, Maj., Corps of Engineers, U. S. A., *Transactions*, Am. Soc. C. E., Vol. LIV, Part A, p. 237.

r. Goodrich. described. The erection of this coal pier was commenced under the direction of the writer, and occupied nearly three years in construction (see Fig. 1, Plate VI). But even this structure does not compare with Coal Dock No. 3 of the Norfolk and Western Railway, at Lambert's Point, Va. It was erected in 1902, and is an excellent example of such structures.[*]

In the coal-handling machinery used by the Delaware, Lackawanna and Western Railroad, at their Hoboken, New Jersey, piers, erected in 1903 and mentioned by Mr. Bensel, New York does possess, however, an example of the very latest methods devised for handling coal. In this arrangement, no storage bins are used, the coal being retained in the cars until called for. The cars are then hoisted and inverted bodily, and the coal is dumped into hoppers which lead through chutes directly into the holds of vessels. Auxiliary screens, bins, hauling engines, and all other necessary adjuncts are included. The estimated capacity of the pier is 2 000 tons per hour.[†] (See Plate VII.)

With the loss to New York Harbor of the bulk of its former grain business, its grain elevator piers have been greatly diminished in number and business. The New York Central Railroad, however, is now constructing an elevator, on one of the Weehawken piers of the West Shore Railroad, containing all the very latest devices and improvements. Fig. 2, Plate VI, is a general view of this structure, which is here shown through the courtesy of H. Fernstrom, M. Am. Soc. C. E., Chief Engineer of the New York Central Railroad. The capacity of the elevator is 2 000 000 bushels, and it is constructed of brick, with a steel skeleton. The superstructure is founded on piles cut off 2 ft. below low water, with concrete up to and including the pier floor. The largest elevator in the United States is at West Superior, Wis., is owned by the Great Northern Railway, is similarly constructed of steel and brick, and has a capacity of 3 000 000 bushels. A decade ago, grain elevators, coal piers, ore piers, etc., were all of wood; to-day fire-proof materials predominate.

In the handling of general merchandise, as Mr. Bensel states, small advance has been made in the past few years. Acres and acres of canal boats and barges may be seen daily, tied up in the slips between open pile piers in some parts of New York Harbor, where they load and unload by hand. At other points are to be seen a forest of spars, recalling the palmy days of the sailing ships of our ancestors. For handling cargo, these vessels generally make use of nothing but their own tackle, with the aid of small floating steam hoists.

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[*] Drawings of this dock may be found in *Bulletin No. 44*, American Railway Engineering and Maintenance of Way Association, p. 26.

[*] *Bulletin No. 44*, American Railway Engineering and Maintenance of Way Association, pp. 13-15, 30-34; also, "Harbors on Lakes Erie and Ontario," by Maj. Kingman.

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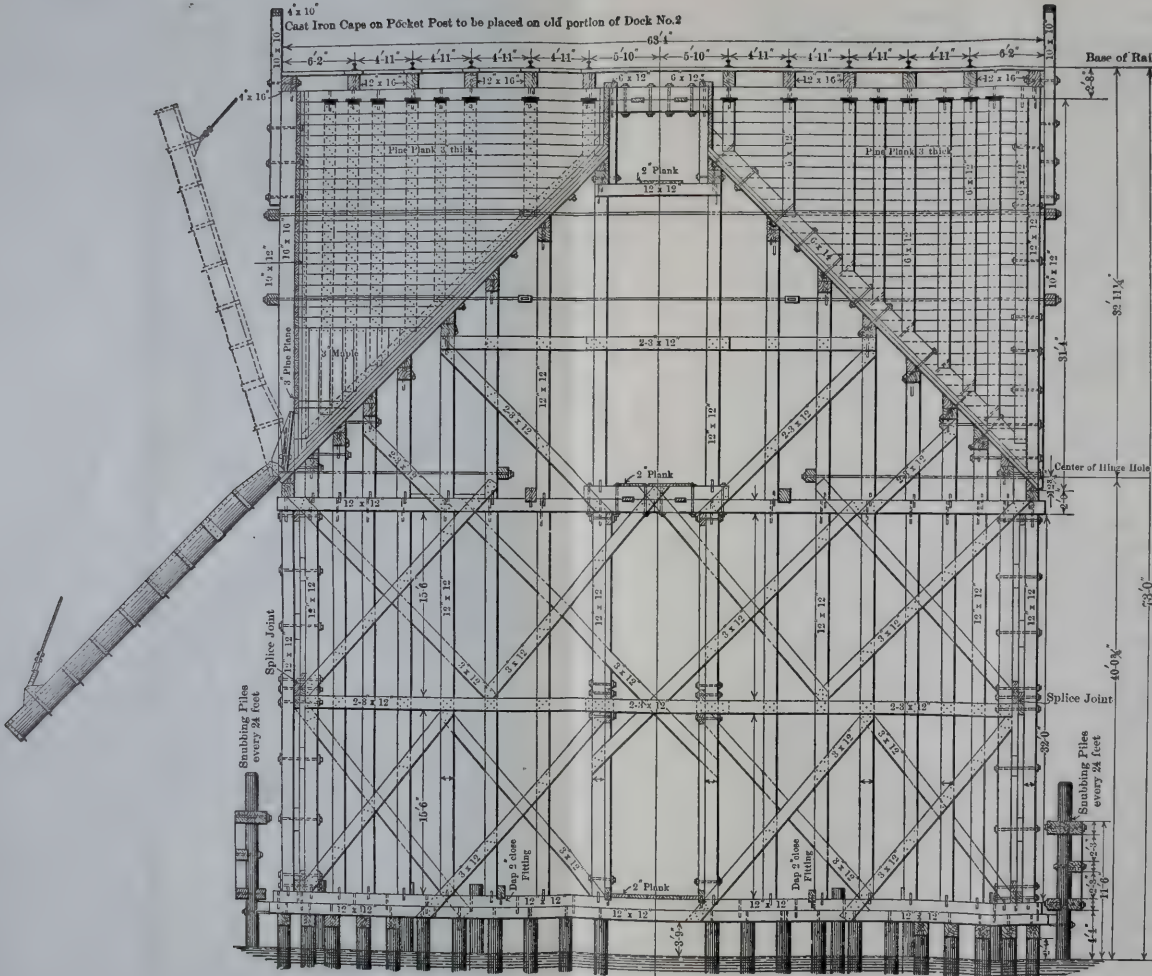
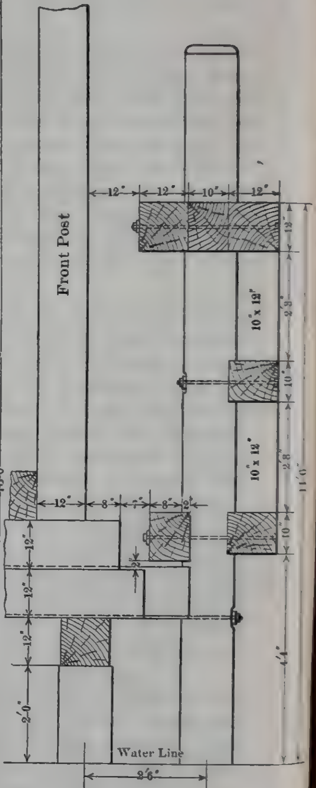
PLATE V. VOL. LIV. PART F
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
GOODRICH ON
WHARVES AND PIERS.



CROSS-SECTION



DETAIL SECTION OF FENDER

ORE DOCK
ALLOUEZ BAY WISCONSIN

Dock extended 600 ft. – Feb. 1902.
Slight alterations in plans.

Mr. Goodrich.

On the newer piers, however, electrically-driven cranes and hoists have been introduced, and electrically-driven trucks, cars, tractors, conveyors, etc., are coming into use to some extent. Railroad tracks and cars are run directly upon most of the larger piers, and, with the growth in the length of vessels, and the corresponding increase in the length and width of piers, it has become imperative to use other means of transportation than hand- and horse-power. Ample fire protection, electric lights, skylights, ventilators, etc., must be provided on a modern pier, where no thought was given to such items a few years ago.

The piers at the Bush Docks, among the largest in New York Harbor, are more than ¼ mile long, and have a double-track, standard-gauge railway throughout the full length of each. They are also equipped with the latest devices in the way of electric hoists, and electric tractors have been used to some extent to displace horse-power. Ample light, both artificial and natural, is provided, together with heat, water, telephone service, etc.

With the exception of the superstructures of the coal and grain-handling piers, few freight-handling pier structures are more than one story high. Many of the Atlantic passenger lines, however, have piers with sheds two stories high, and most of the ferry-houses are being constructed in this way. Notable among the former are the piers of the North German Lloyd Steamship Company, at Hoboken, N. J., which have just been reconstructed (see Fig. 1, Plate VIII). They are of steel throughout, carefully protected from fire, and cost about $4 000 000. The substructure, however, is of wooden piles, but the pier platform has a concrete top.*

The passenger and truck-handling ferries of the Pennsylvania Railroad, for instance, have terminals which include, besides passenger waiting-rooms on two floors, with retiring-rooms, dining-rooms, baggage and express offices, ticket and executive offices, etc., also covered cab stands, street-car terminals, etc., making them in all respects regular railroad terminal stations. The ferry racks are usually of oak throughout, the bridges are over-head hung, and are built to serve both decks of ferry boats (see Fig. 2, Plate VIII). The approaches are always on piles, and the ferry-houses, also, in most cases. Many other railroads have terminals equally well built and equipped, and many of the terminals constructed by special ferry-companies and other parties, and catering to special districts, are equal in many respects to the best. While the general type of construction is old, still many new features have lately been introduced, notably the two-story feature, and the over-head support of the bridges at their outshore ends. The ferries leading to Staten

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* "North German Lloyd Piers," *Engineering Record*, Vol. XLV, pp. 578, 611; Vol. XLVI, pp. 8, 58.

Mr. Goodrich. Island, and to the vicinity of the Bush Docks, are about to be reconstructed, in large part along the very latest lines.

Some piers have been built especially to cater to particular trades. Thus, of late, fruit piers must be steam-heated and specially ventilated, while the insurance rates dictate that naval stores go principally to one open wharf, etc., etc. The railroads have developed special devices in connection with their car ferries, so that in the best of them the outshore ends of the bridges do not rest on pontoons, as formerly, but are suspended from over-head, and are adapted to the rise and fall of the tides by electrically-driven winches. The terminal of the West Shore Railway at Weehawken is so constructed, and others are building.

In New York City, with the purchase by the city of so much of the water frontage, private enterprises have not been exploited as much as in other cities. Aside from the municipal property, the railroads own most of the best specimens of each class of construction. All the vessel repair work is in private hands, except that of the Navy. The private repair wharves, piers, docks, marine railroads, etc., are fairly numerous, and well equipped, while those at the Navy Yard are capable of repairing and building the largest battleships. At the Navy Yard, the constructions are of the most permanent sort, with concrete walls, filled piers, steel superstructures, etc., with pneumatic and electric equipment, etc.; while those owned by private concerns, are, for the most part, of a much lower grade of construction, though fully capable of turning out good work.

Of the private water-front companies, the Brooklyn Wharf and Warehouse Company and the Bush Terminal Company operate the most extensive enterprises. Each of these companies owns one or more of most of the different varieties of structures mentioned above, the latter company having newly constructed and equipped structures throughout.

In the United States the pier superstructures are not used as warehouses, as is so generally the practice abroad, principally for the reason that the piers are on pile foundations and are too narrow for the combined warehouse and pier traffic. The pier shed is usually brought only to the bulkhead line, and a wide open passage is left along the water front. Back of this open planked or paved wharf are placed the warehouses, power plants, cold-storage houses, railroad yards, and other auxiliary structures, which go to make up a complete steamship terminal.

The information given in Mr. Bensel's paper concerning the alteration of the tidal level of New York Harbor is most interesting. It is a rather peculiar fact, however, to be seen in the tide curves given, that, while the highest tides and the mean low tides are ap-

Mr. Goodrich.

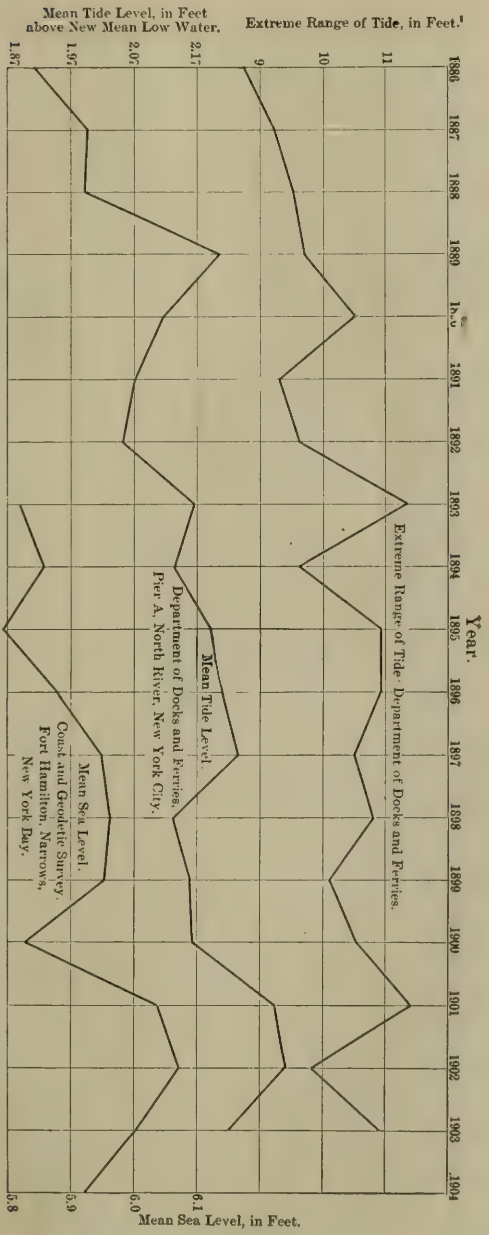

FIG. 3.

Mr. Goodrich. parently rising, the lowest tides are practically stationary, or have been rising for only the past ten years. This is clearly shown when the extreme range of tides for each year is plotted. That curve shows an increasing extreme range from 1886 to 1893, after which the range remains practically constant. (See Fig. 3.)

The Superintendent of the Coast and Geodetic Survey, in response to an inquiry by the writer, replied in the following most courteous and interesting letter:

"Sir:—In reply to your letter of the —— instant, I have to state that this Survey has no information which would enable one to state positively whether the shores of New York Bay are rising or falling.

"We have had tidal observations at various stations in the vicinity of New York for more than fifty years, but for most of that period no record was kept of the relation between the zeros of the various tide staves used, thus rendering it impossible for us to use the observations as a continuous long series. The most carefully conducted series of observations we have in New York Harbor is that which is now being made at Fort Hamilton, at the Narrows, N. Y., where we have the results for eleven years, which are as follows:

"MEAN SEA LEVEL ON THE TIDE STAFF AT FORT HAMILTON, N. Y., FROM 1893 TO 1903.

Year.	Mean. Ft.	Year.	Mean. Ft.	Year.	Mean. Ft.
1893	5.817	1897	5.947	1901	6.035
1894	5.854	1898	5.962	1902	6.071
1895	5.790	1899	5.953	1903	6.004
1896	5.877	1900	5.824	1893–1903	5.921

"While these means fluctuate slightly, there appears to be in a general way an increase throughout the period. From spirit-levels between our tide staff and bench-marks on shore, made at intervals throughout the period of observations, it appears that the staff is stable with reference to these marks. Hence, one might readily infer that the shore is sinking at the rate of about 0.02 ft. per annum, or 2 ft. per century.

"But, one should be cautious in drawing such a conclusion from these results, for other causes may operate to produce the observed variations in mean level. It seems probable that differences in the annual rainfall will affect mean levels slightly, and variations in the mean annual pressure of the atmosphere must directly affect mean sea level. A comparison has been made between the mean annual barometer readings and the above mean sea level values, which, although not entirely satisfactory, seems to suggest that much of the fluctuation in the mean annual level of the sea is due to variations in mean atmospheric pressure. As our barometric observations are now confined to the land, it is not always possible to infer correctly whether the pressure over the adjacent water is greater or less than at the station. If we could obtain barometer readings every day throughout the year at selected stations out at sea, there is but little

PLATE VI. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
GOODRICH ON
WHARVES AND PIERS.

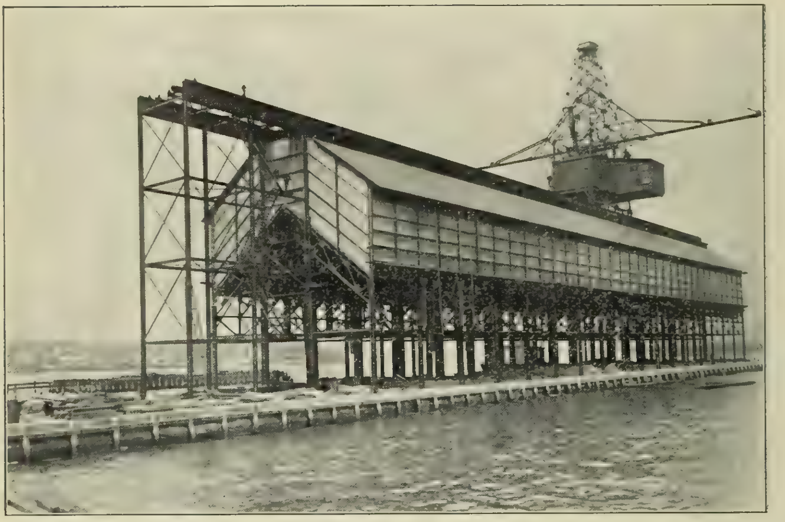

FIG. 1.—COAL PIER, NEW YORK NAVY YARD.

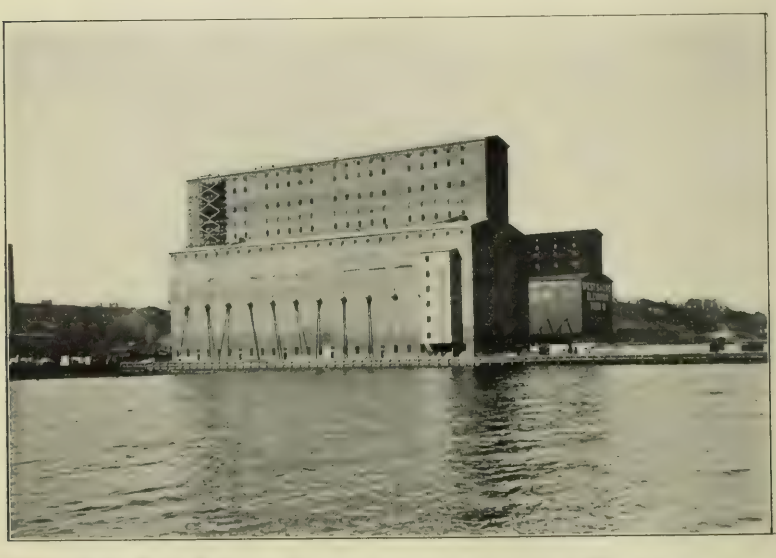

FIG. 2.—GRAIN ELEVATOR, NEW YORK CENTRAL RAILROAD, WEEHAWKEN, N. J.

doubt that we could account for most of the observed variations in annual mean sea level. Mr. Goodrich.

"Respectfully yours,
"O. H. TITTMANN,
"*Superintendent.*"

The tidal observations given above tend to confirm those of the Department of Docks and Ferries of New York. (See Fig. 3.) It may be of further interest to quote from Folio 83, Geological Atlas of the United States, New York City Folio, p. 3, as follows:

> "At an epoch not yet well determined the land stood about 200 ft. higher than it now stands in reference to sea level, and the streams in consequence sunk their channels deep. * * * The old channel is traceable by soundings. When the land sank to its present level, the valleys were submerged, and the harbor of New York resulted."

One might infer, from Mr. Bensel's data and that of the Coast and Geodetic Survey, that this subsidence was still in progress, but one must keep in mind, however, the reservation of Mr. Tittmann.

It is most fortunate that the range of tides along the shores of the United States is so small, as it greatly simplifies the harbor constructions. The only points where a range of water level is to be found at all comparable with the tidal variation at Liverpool, Havre, Antwerp, etc., are in cities on the St. Lawrence and on the Mississippi and its branches, where the range from flood to low-water level rivals the European cities above mentioned. At such points special devices are resorted to for the handling of freight and passengers between shore and boat, but nothing of special note can be mentioned except such as have grown out of the levee systems which have been constructed along the banks of most of the rivers in the Mississippi Basin within the last few years.

Where there is an extreme range of water level, it is not usual to find the use of piers so pronounced as where the range is less. Perhaps this is due to other causes, but the fact remains that where there is a high variation in water level, the cost of structures of the nature of piers is high. Of course, the first and greatest desire, with such a range, is to diminish, as far as possible, the variation of water level, for practical reasons connected with the loading and unloading of cargo, and an enclosed basin is resorted to whenever possible. These basins are often nothing more than elongated and enlarged slips cut into the land and provided with regulating entrances, but where they can be constructed of sufficient size, piers are built out into them. In such cases, the slip with its bounding wharves is the portion to which attention is turned, while in localities with small tide variation, it is the pier structure. On this point, a good idea of the English practice is to be formed by consulting a paper entitled "Dock Improvements at Liverpool,"* by George C. Kenyon, Assoc. M. Am. Soc. C. E.

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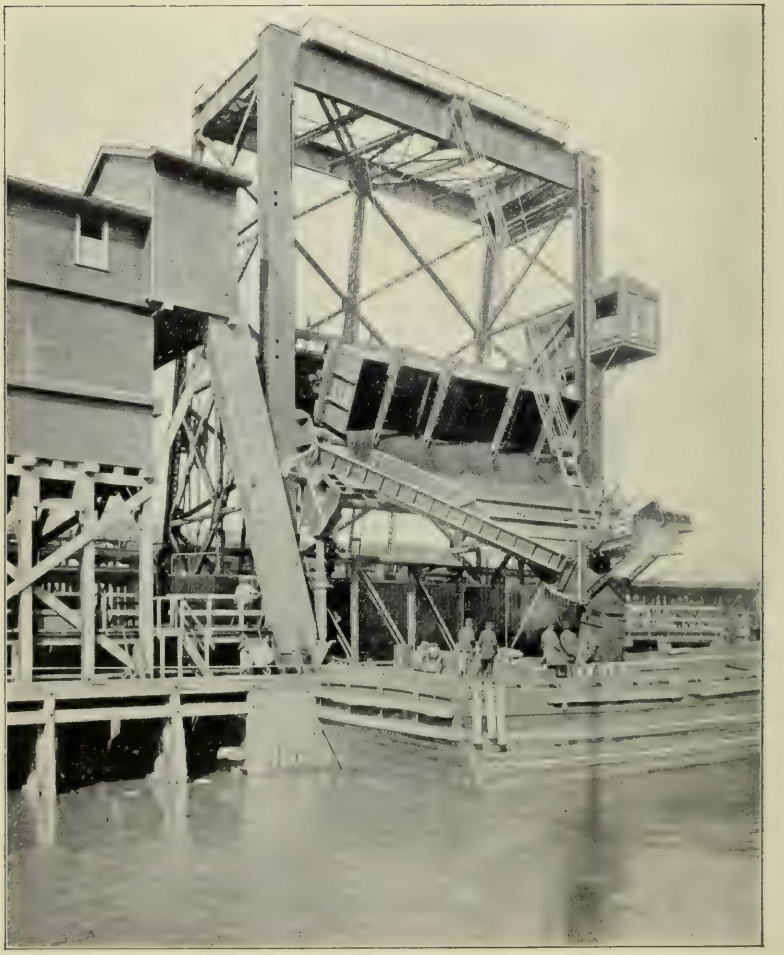
* *Transactions*, Am. Soc. C. E., Vol. LII, p. 36.

Ir. Goodrich. Where there is not a large range of water level, a basin, in the sense used above, loses its advantages and even possesses decided disadvantages, from the restricted entrance, the necessity for turning vessels in a restricted space, etc. Where a protection is needed against storms, and a basin is resorted to, it is in reality a small harbor, and would not belong in the class with basins or docks within harbors.

With rivers subject to flood, every precaution is taken not to restrict the area of flow in any way; and so piers with vessels moored alongside them are not available. The cost of building such a structure, capable of withstanding floods, would be prohibitive. The cost of extra real estate along the banks, and of the extra length of haul of freight and passengers being more than offset by the extra cost of the structure. On the other hand, in any localities where piers are allowed at all, they may just as well be made of solid construction, where they can have width enough to make that variety economical. This may roughly be placed at 100 ft. and more, for ordinary depths of water and kinds of bottom. Such piers have the advantages of greater stability, less combustibility, and usually cheaper first cost, and an equally long, if not longer, life. The only known disadvantages are the longer time of first construction, and the period which must be allowed for the settlement to take place, which always occurs in every artificial fill. Plate IX shows cross-sections of the piers at the Bush Docks and the slips between them, and of such as are being built in the North River by the Department of Docks and Ferries and the slips between them, and illustrates graphically the advantages and disadvantages described above.

On the other hand, one of the objections usually urged against solidly filled piers, that of entirely cutting off the tidal flow and restricting the area of the tidal prism, is practically groundless, because a modern ship, drawing from 25 to 35 ft. of water, lying alongside a pile pier (which is not usually a score of feet longer than the vessel itself) forms a most effectual obstruction to the flow of water through the pier substructure. When the ground under the center of the pier is brought up by artificial filling as high as it should be to secure the greatest stability, and where the depth of water in the slip is barely enough to float the vessel at low tide, as is usually the case, there can remain but a small percentage of the velocity of flow of the stream itself under the pier, so that its total loss would be practically nothing.

Although piles may be used profitably for the support of the working platform of narrow or other small-dimensioned piers, it is clear that some more permanent construction is better for the larger ones, and also more especially for the wharves along the water front of a large city, out from which the piers may be afterward built.



Car Dumper Used by the Delaware, Lackawanna and Western Railroad at Their Hoboken, N. J., Piers.

Mr. Goodrich. In general, such work comes under the heads of harbor work and water-front protection, and doubtless will be considered under those heads before the Congress, but, wherever the structures are built primarily as wharves, they should be considered in the general topic under discussion. The disuse of piles is especially important where the harbor water contains the teredo, or other factors causing the destruction of timber. Where special permanence is not necessary, the ordinary stone-filled crib bulkhead, either sunk upon the bottom of the harbor, or resting upon piles cut off at low-water level, may be used. In place of a crib, a braced-pile structure, with or without rip-rap and tie members, is sometimes used in conjunction with sheet-piling on either the water or the land side of the piling.

It was such a design as this, with the sheet-piling on the inside, which the writer used around the whole exterior of the large piers, and along the bulkheads of the Bush Docks (Plate IX). In the case of the piers, the two sides are tied together by steel tie-rods and rip-rap is used to assist the sheet-piling in retaining the center fill. It is this method of construction to which Mr. Bensel refers in his paper.

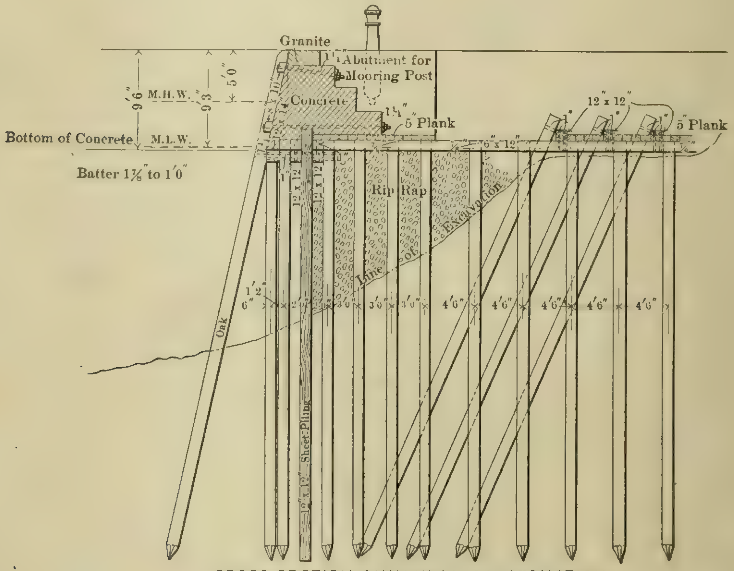
At the Navy Yard, in Brooklyn, the sheet-piling is 12 in. in thickness, grooved and splined, and is driven in front of the pile structure near the face of the bulkhead. (See Fig. 4.) Often, the sheet-piling is replaced by round piles closely driven.

Of course, such wooden structures cannot be used unless the water is free from teredo and other similar causes of destruction. In case of their presence, a concrete face must be placed in front of the crib or front piling, as was done at the Navy Yard at Boston. The piles themselves may be encased in concrete, as has been done in San Francisco, or the whole wall may be constructed of such material. Sometimes a concrete top, from low-water level up, is used in connection with a pile support. This is the general method in use at the New York Navy Yard, and, to a less extent, in some other portions of New York Harbor. (See Fig. 4.) In such cases a platform is constructed at low-water level, on which to place the concrete wall. In other walls in the harbor, the platform has been constructed by a diver on the harbor bottom, at which level the piles have been cut off, or in some instances at some distance above the bottom, and the piles may or may not be clamped, according to circumstances. (See Fig. 5.) At present, the method used by the Department of Docks and Ferries of New York City is simply to lodge the 80-ton concrete blocks directly on the pile heads. (See Fig. 6.) In some instances, concrete has been placed *en masse,* usually behind a facing of blocks, however; but the present practice is to build the whole wall of concrete blocks of large size for the portion below low water, and of smaller blocks of granite above low-

Goodrich. water level. Sometimes this upper portion is built of concrete *en masse,* either behind a veneer of granite, or forming the whole wall.

Whenever possible, the wall is lodged directly on the rock bottom, but long stretches are supported on piles, usually uncapped and unclamped.

The degree of success which has been attained in the construction of walls in this way is high. Even where the ultimate support is upon the mud alone, through the agency of piles, the settlement has been comparatively small, where the wall has been carefully designed. At one point, however, it has reached a maximum of 5 ft. 6 in.



CROSS-SECTION QUAY-WALL CONSTRUCTION
USED AT NAVY YARD, NEW YORK.

Fig. 4.

The writer is sorry Mr. Bensel did not give some description of this work, as it is most interesting, and if treated in the style of his paper in general, would have been of great value.

The use of concrete piles on piers has not yet been tried for marine work in the United States, as far as the writer is aware.

The writer cannot agree with Mr. Bensel when he says that the "carrying power of piles is to a great extent a matter of conjecture, except where determinations are made by experiment," unless he includes under the word, "experiment," the observations of the last

Mr. Goodrich.

CROSS-SECTION OF
BULKHEAD OR RIVER WALL
AS BUILT ON
NORTH RIVER
1876-1898.

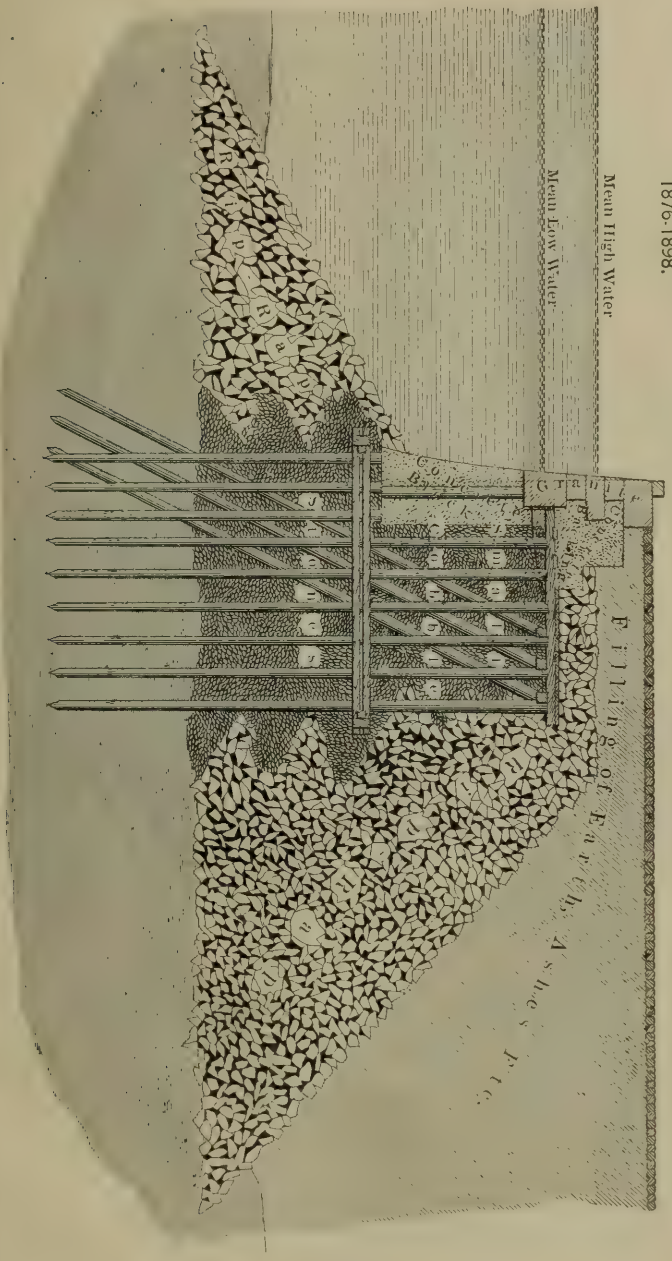
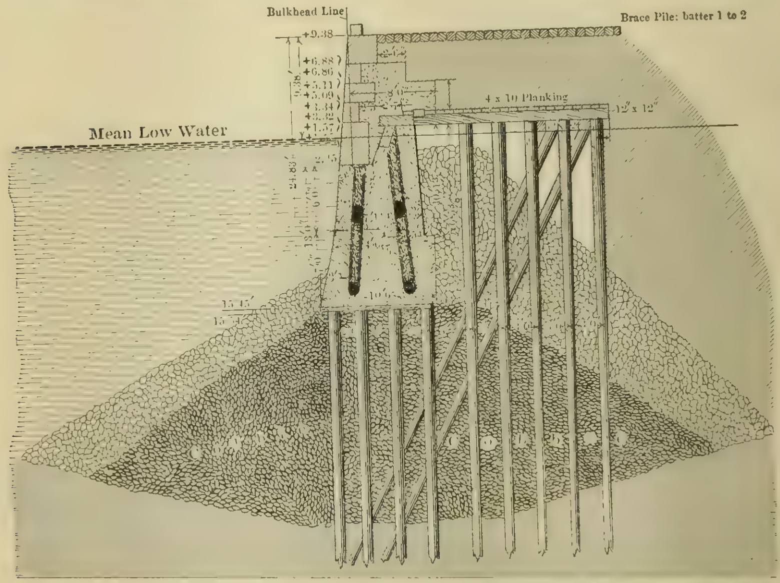


Fig. 5.

Mr. Goodrich. blow of the hammer, and the resulting penetration. The writer believes that the "conjecture" is usually as to the supporting power of the soil, unless direct observations or experiments are made.

Too little attention is usually paid by engineers to the action which piles will have upon the earth into which they are to be driven. Their usual care is only to see whether or not the piles can be driven until their points rest upon rock, or penetrate some hard stratum which is likely to give sufficient bearing power for the purpose at hand, and they then let the piles act as columns. Every one who has caused excavating to be done to any depth around piles driven on land, or who has seen a cluster of piles driven in deep water and left unfastened, knows the large number of piles which find final lodgment in far from vertical positions, and which, in order to work them into the completed structure, usually have their free ends forcibly drawn into position, thereby setting up in the pile large intitial bending strains, due to the curved shape induced. Furthermore, such bent piles and all naturally crooked sticks have other excess strains induced by immoderate loads. It is believed from examination of Plate III of Mr. Bensel's paper that Pile 2 of Group 2 was the cause of the failure described by him, and that it



Foundation and platform piles spaced 4 ft. centres longitudinally, except in front row, " 2 ft. "

MODIFIED WALL OF 1899.

FIG. 6.

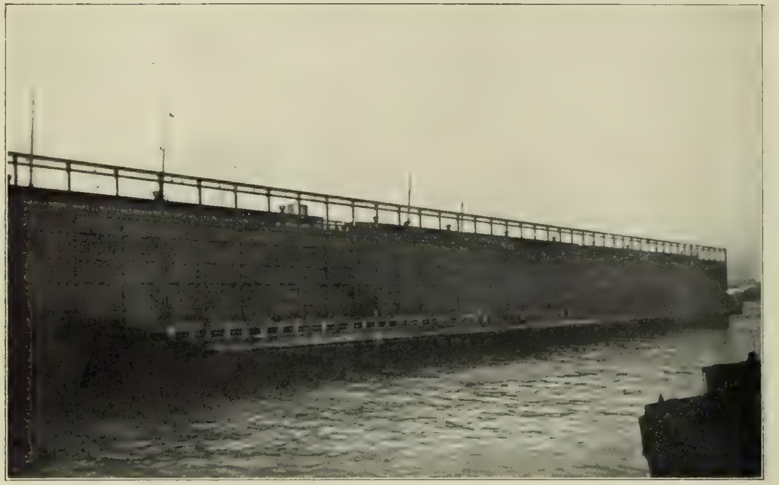


FIG. 1.—PIER OF NORTH GERMAN LLOYD STEAMSHIP COMPANY, HOBOKEN, N. J.

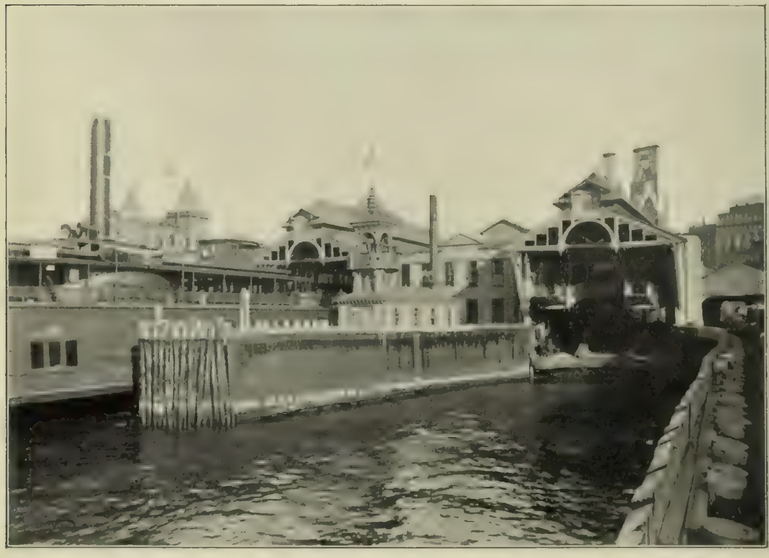


FIG. 2.—FERRY SLIP, PENNSYLVANIA RAILROAD, NEW YORK CITY.

was due to just the cause cited above. Inquiry, among those conversant with the test, has also increased the strength of the writer's opinion in this regard. **Mr. Goodrich.**

Where piles are carried principally by surface friction, still other elements enter to complicate the problem. The first action of a pile is to compress the earth in the near neighborhood of the place of driving. Round 12-in. piles, driven at the following distances from center to center, compress the soil to the corresponding percentage of its original volume:

Distance from center to center, in feet.	Percentage of original volume.
1	20
1.5	65
2	80
3	90

When it is known that the percentage of voids in few earths is above 45, the well-known fact of the practical impossibility of driving piles closer together than 3 ft. from center to center, without disturbing others in the neighborhood, is readily understood. Further, if it be assumed that the angle of internal friction of earth be such as to make its lateral pressure 0.4 of the vertical, and its supporting power 0.16 = (0.4 × 0.4), the following table gives the center to center spacing which would give, at the depth reached by the point of the pile, a supporting power equal to the theoretical frictional resistance between the pile and the earth (0.7 being assumed as the tangent of the angle of friction of earth and wood):

Depth of pile in ground..	10	20	30	40	50	60	70	80	ft.
Spacing of piles to develop full earth pressure.....	6.0	7.4	9.0	10.4	11.6	12.8	13.8	14.8	"

Of course, where the earth is not of practically uniform density throughout, but increases with the depth, as is usually the case with the upper strata (15 ft., say) of the muddy bottoms of rivers, the spacing would be less for any given depth of penetration. The foregoing two facts show conclusively that piles spaced only 2½ ft. apart, as was the case in the pairs of piles of Group 3 of the test described by Mr. Bensel, will act together, and his curves show that in almost every case the two piles of a pair settled with wonderful uniformity. Apparently, each group of four piles was 6 by 12 ft., outside dimensions. The diagrams also show that the pair of piles which were nearest together (6 ft.), of each group of four, also settled more nearly together than the pairs taken the other way (12 ft. apart), showing that in the silt encountered, piles influence each other when driven not more than 6 ft. apart, thus incidentally proving to some extent the truth of the foregoing assumptions and line of reasoning.

Mr. Goodrich. It is also to be noted that all platforms settled practically as much as the groups in connection with them, further proving the assumptions.

In most cases in which engineers try to apply pile-driving formulas they are absolutely inapplicable. A formula which is made to apply to a pile, months, weeks, or even days, after its driving, is nothing more than a crutch with which to make a guess. The act of driving, especially if the pile be at all crooked or springy, and the earth at all stiff, leaves the pile standing in an enlarged, irregular hole, wherein the earth presses but slightly against the pile. Repeated hammer tests made by the writer on piles left to stand for a few days showed lessened penetrations under equal blows, amounting to only one-twentieth of the original in some few cases with silt, and varying from one-fifth to four-fifths under usual circumstances. With sand, and with the point of the pile not in a hard stratum, the penetration is not usually lessened so much, from four-fifths to one-half being the average relative amount. One pile tested at increasing intervals of from 10 minutes to 30 hours, showed a decided decrease in penetration at first, with a rather sudden turn toward a uniform value after a certain interval, so that the curve resembled an equilateral hyperbola with a small radius of curvature at the vertex.

So little is known of this action of increasing the supporting power, that the use of a formula to give ultimate supporting power is untrustworthy, and its further use to give the supporting power of what is really the earth is altogether wrong.

In the tests described by Mr. Bensel, what his department really wanted was the supporting power of the mud at different depths to which piles might be driven. This was ascertained by the tests made and the observations of the resulting settlements under increased loadings. Of course, a pile formula would not apply to the conditions encountered, one pile evidently failing as a column, and the whole earth mass settling in all cases, and its experiencing local settlements around groups of two piles in special cases.

When the writer's pile formula is applied:

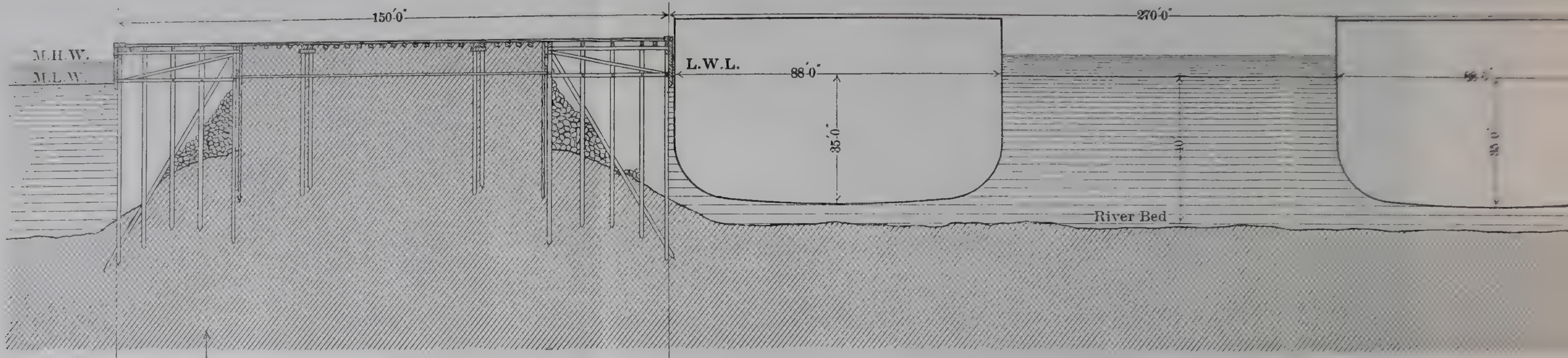
$$\text{Load, in tons} = \frac{10 \times \text{fall of hammer, in feet} \times \text{weight of hammer, in tons}}{3 \times \text{penetration of pile, in inches}},$$

it is believed that some close approximation will be obtained as to what increments of load will cause sudden settlement of the pile through the earth. The averages of the results of the formula obtained for Groups 1, 2 and 4 of Mr. Bensel's paper are as follows:

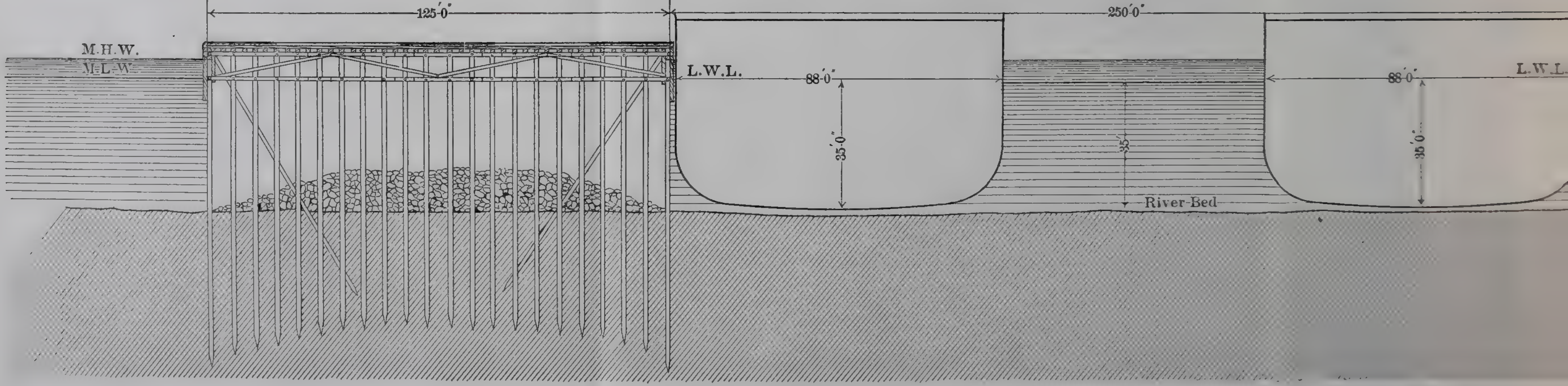
Group 1....................	4.9 tons.
" 2....................	13.9 "
" 4....................	15.6 "

ch.

CROSS SECTION OF PIERS AND SLIP, BUSH DOCKS.

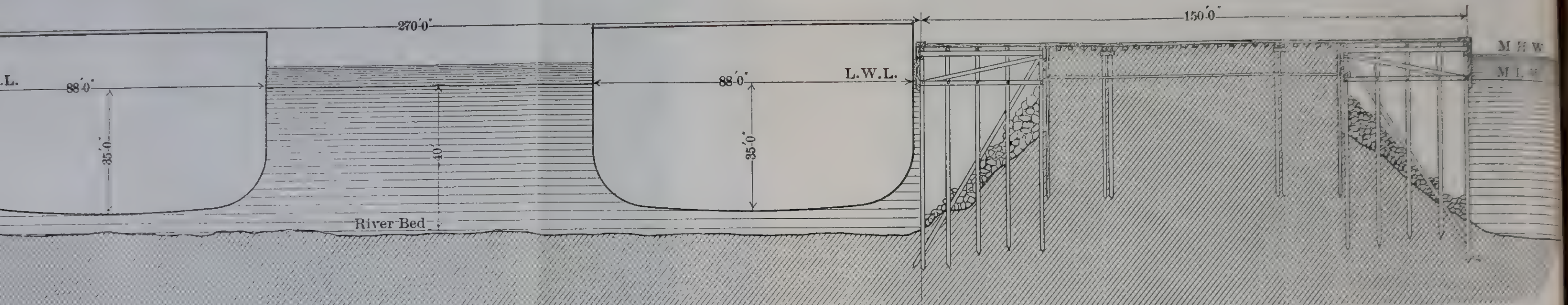


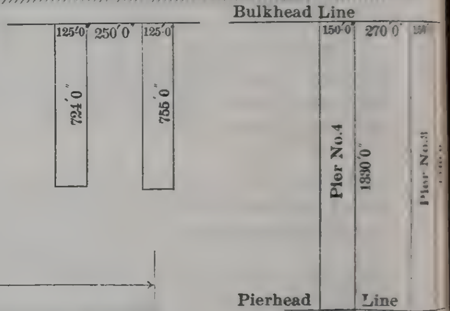
CROSS SECTION OF PIERS AND SLIP, NORTH RIVER.



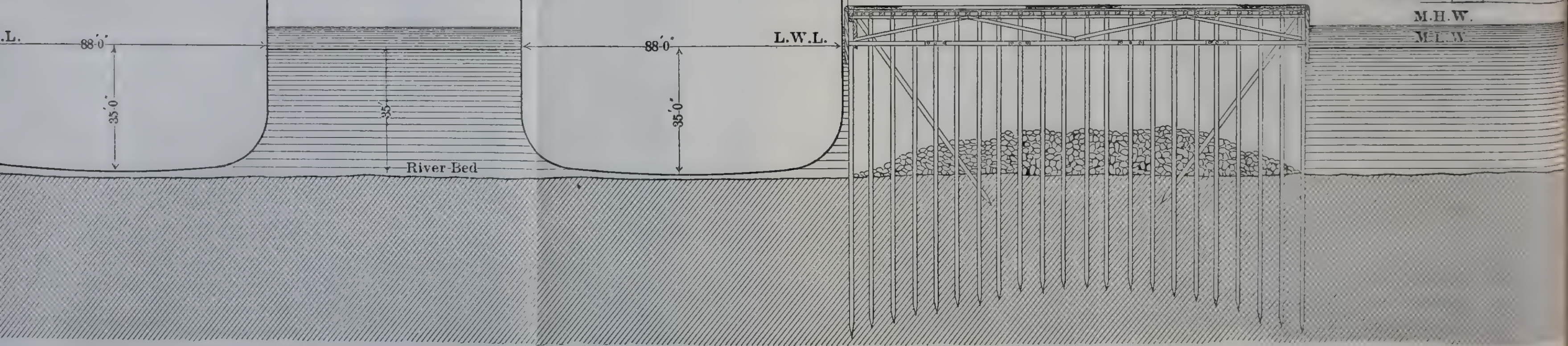
NOTE:- Approximate Hull Section of S.S. BALTIC shown in each Slip.

CROSS SECTION OF PIERS AND SLIP, BUSH DOCKS.





CROSS SECTION OF PIERS AND SLIP, NORTH RIVER.



NOTE:- Approximate Hull Section of S.S.BALTIC shown in each Slip.

Mr. Goodrich.

Examination of the curves of his paper shows that in Group 1 sudden settlement occurred twice with increments of 7.2 tons and 6.7 tons, respectively; in Group 2, with 11.7 tons and 6.7 tons, respectively (the latter only ⅛ in.), while, in Group 4, with increments of 4.6 and 4.8 tons, the settlements were only eighths of inches. The three last noted amounts may be entirely due to natural compression of the timber, and of the joints, and of bending of the piles. Consequently, only the observations on Group 1, and perhaps the first one of Group 2, are properly to be considered. It is believed that these show a close agreement with the phenomena anticipated from the results of the writer's formula.

The results of lagging piles, to secure a greater area of bearing, appear to be advantageous when viewed simply in the light of the relative penetrations secured by a given fall of hammer. In Mr. Bensel's table, if the supporting power of each pile in Groups 1, 2 and 4 is computed by the writer's formula, and the results for each group averaged, the supporting powers found are as follows:

Group.	Supporting power.	Lagged or not.	Ratio of lagged to unlagged.
1	4.9	no.	....
2	13.9	yes.	2.83
4	15.6	yes.	3.18

If the cost of the unlagged and of the lagged piles be compared, on the basis of $10.40 per pile, $3.60 for driving, and $30.00 for timber in place, the ratio of supporting power per unit of cost is as follows:

Group.	Supporting power, ratio lagged to unlagged.	Cost in place.	Ratio of costs.	Ratio of cost per unit supporting power, lagged to unlagged.
1	....	$14.00	....	....
2	2.83	26.00	1.85	0.65
4	3.18	28.00	2.00	0.63

The query immediately arises as to what the effect of the lagging will be on the increase of surface friction which is always found to occur by lapse of time.

It might be expected that the enlarged area of the end of the pile would break up the earth so much that little or no increase would be expected for some time, but that ultimately there would probably be found an increased resistance.

The only experiments, with which the writer is acquainted, which bear at all upon this point, were made by the Department of Docks and Ferries of New York City some years ago, and the writer's acquaintance with them is due to the courtesy of the officials of that Department. Three piles were driven, one plain, the other two spliced, and in a manner very similar to that used for doing lagging. One spliced pile was driven to the same depth as

Mr. Goodrich. the unspliced one. During driving, the usual observations were made, and, after a lapse of three days, the piles were each driven several feet further. The supporting powers, as given by the writer's formula, were as follows:

Length.	Spliced or not.	Length in ground.	Supporting power, first driving.	Supporting power, second driving.
85	no.	65	8	120
100	yes.	65	16	80
100	yes.	80	8	120

The high supporting power of the second pile at first driving is rather strange, but the relative increase, after the lapse of three days, is all the more striking. It thus appears that the unspliced pile, 85 ft. long, was better than a spliced one even 100 ft. long. Of course, these values cannot be used without danger in designing pile structures, but rather one should use the supporting power of the soil.

Returning now to the subject of lagged piles, it is seen that the ultimate supporting power is likely to be much less for the lagged than the unlagged, by much more than enough to compensate for the relative initial less first cost of the lagged piles per unit of supporting power.

It is the writer's decided opinion that the lagging of piles is unnecessary, and even relatively costly; that piles driven in mud will develop the full supporting power of the soil, and often of their carrying capacities as columns, if driven 40 ft. or less into firm ground. With ordinary varieties of earth, this safe supporting power, at the depth mentioned, is approximately 35 tons. It must not be forgotten, in this, that earth is usually compressible, and a certain amount of settlement of piling must always be expected.

The supporting power of pointed or blunt piles is not found to vary perceptibly. In driving a blunt pile, a cone of compressed earth forms under the flat end and acts in all respects like a wooden point,* except that the pile is more apt to shear to one side when driven with such a point than when the point of the pile is carefully cut to a fairly good cone.

The usually given crushing value of 10 to 14-in. wood columns is much higher than 35 tons per column, but with the usual methods in vogue, in which large initial stresses are to be expected, it is not safe to use piles of diameters which would be just large enough to support the developed supporting power of the earth, nor would it be practicable to secure or drive them.

It is to be regretted that more experimental information is not available as to this subject, and it is hoped that engineers will take every opportunity of securing such data.

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* "The Supporting Power of Piles;" *Transactions*, Am. Soc. C. E., Vol. XLVIII, p. 180.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

TESTS OF MATERIALS OF CONSTRUCTION.

Congress Paper No. 76.

TESTS OF MATERIALS OTHER THAN METALS.

By Edouard Candlot, Ingénieur Civil, Paris, France.

Congress Paper No. 77.

TESTS OF CEMENT.

By W. A. Aiken, M. Am. Soc. C. E., Pittsburg, Pa., U. S. A.

Congress Paper No. 78.

TESTS OF STEEL.

By L. Baclé, Ingénieur Civil, Paris, France.

Congress Paper No. 79.

TESTS OF STEEL.

By William R. Webster, M. Am. Soc. C. E.,
Philadelphia, Pa., U. S. A.

Congress Paper No. 80.

TESTS OF TIMBER.

By Gaetano Lanza, M. Am. Soc. M. E., Prof., Theoretical and Applied Mechanics, Massachusetts Institute of Technology, Boston, Mass., U. S. A.

Discussion on Tests of Cement by

James E. Howard, Watertown, Mass., U. S. A.
F. Schüle, Zurich, Switzerland.
L. J. Le Conte, Oakland, Cal., U. S. A.
J. A. Fairleigh, Louisville, Ky., U. S. A.
Frederic P. Stearns, Boston, Mass., U. S. A.
Richard L. Humphrey, Philadelphia, Pa., U. S. A.
Edouard Candlot, Paris, France.
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Discussion on Tests of Steel by

Gaetano Lanza, Boston, Mass., U. S. A.
F. Schüle, Zurich, Switzerland.
Sir William H. White, London, England.
A. A. Stevenson, Burnham, Pa., U. S. A.
J. P. Snow, Boston, Mass., U. S. A.

Discussion on Tests of Timber by

W. K. Hatt, Lafayette, Ind., U. S. A.
James E. Howard, Watertown, Mass., U. S. A.
Sir William H. White, London, England.
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Paper No. 76.

TESTS OF MATERIALS OF CONSTRUCTION.

TESTS OF MATERIALS OTHER THAN METALS.

By Edouard Candlot.*

Translated from the French by
Paul A. Seurot, M. Am. Soc. C. E.

Very few changes have been made during the last ten years in the methods used in testing limes, cements, mortars, stones, etc. The same methods and the same machines are still used, but great progress has been made in the regulation and standardization of these methods.

Until 1890 there was no precise rule governing the execution of tests; each experimenter followed his own ideas, often using very different methods. The interpretation of the results was necessarily very difficult because it was impossible to compare tests made in several laboratories; the strict requirements of the specifications caused a great deal of trouble for manufacturers who did not know how to meet requirements which were often contradictory.

A Committee on Tests of Materials of Construction, appointed in 1891 by the Minister of Public Works, has done a great deal in framing precise rules for the execution of all tests. After several learned reports based upon numerous experiments, the Committee recommended certain rules and methods to be followed in testing materials, which have been generally adopted in France, and which have reduced specifications to a small number of uniform type, giving satisfaction to those using the materials as well as to the manufacturers.

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* Ingénieur Civil.

We will rapidly review the principal tests in general use and will try to show, at the same time, the improvements which have been made.

In tests of lime and cement, the following points are usually investigated:

Chemical composition,
Apparent density,
Fineness of grinding,
Initial and final sets,
Constancy of volume,
Tensile and compressive strength.

There is nothing special to say in regard to the chemical analysis, which is done in the usual way adopted in all laboratories.

The test of apparent density was one for which the rules had the least precision; it consists in slowly filling a given measure, usually 1 liter, so that the powder will not settle. Formerly this test was made by various other methods, all very imperfect and giving unsatisfactory results which were not in agreement. The Committee on Tests adopted an apparatus consisting of a funnel with sieve with which it is possible to fill the measuring box in a uniform way. The box itself, which before was of indefinite, is now of fixed dimensions; it is a cylinder with a capacity of 1 liter and measuring 0.10 m. in height.

The fineness of grinding of limes and cements was formerly determined with sieves having 324 meshes per sq. cm.; sieves with smaller meshes were rarely used; but now sieves having 900 and 4 900 openings to the sq. cm. are used for cement, and sieves with 900 and 2 500 openings, for lime. The gauge of the wire is also determined for each of these sieves.

The time of setting is still determined by means of a Vicat needle; but this needle, which as devised by Vicat was nothing but a common darning-needle filed squarely at one of its extremities and loaded with a lead weight of 300 g., is now an improved instrument. It is a rod sliding in a frame, which may be stopped by a set screw at any point of its course. The needle fixed at the lower extremity is cylindrical and has a cross-sectional area of 1 sq. mm.; a pointer fixed on the rod moves in front of a graduated scale which indicates the penetration of the needle in the mortar. The whole apparatus weighs 300 g. This apparatus enables the experimenter not only to determine the time of final setting, that is, when the needle cannot penetrate any farther into the mortar, but also when the initial set begins, that is, the time when the needle cannot penetrate completely throughout the sample and consequently when the mortar, losing its plasticity, will harden more and more.

The tests made to determine the constancy of volume, are those which have been improved most during the last ten years. They consisted in examining cakes immersed in water at a temperature of 15 to 18° cent. Under these conditions it was necessary to wait a very long time before one could have any idea of the quality of the cement; and even then the cake had to be made with unusually poor cement to show any signs of alteration at the end of a few weeks. Tests made at a warm temperature have given results in a shorter time and with more precision. The improvements made in this method of testing are due chiefly to M. H. Le Chatelier, who designed, to that end, a simple and handy apparatus, called the needle mould, which enables the experimenter to ascertain with sufficient precision the extent of deformation. This mould consists of a brass cylinder measuring 0.03 m. in diameter and 0.03 m. in height; it has a longitudinal slot parallel to its axis and on each side of this slot are fixed two needles, 0.15 m. long. The mould is filled with the mortar to be tested, and after 24 hours, or after the time necessary for setting has elapsed, the whole is immersed in water at 15° cent. which is brought subsequently to the boiling point. After three hours during which the water is constantly maintained at 100° cent., the mould is taken out of the water and the distance between the needles is measured; if there is any expansion of the cement, it would be so multiplied that the least motion could easily be detected. The relative displacement of the points of the needles may be compared to the lineal expansion of a block measuring 0.60 m.

The test at warm temperature detects in a few hours the action of expansive materials; it easily reveals the presence of even very small quantities of free lime. One may say that its adoption has brought about great improvement in the manufacture of hydraulic cements.

Tests to determine the tensile strength are always made with samples having the shape of an eight and with a cross-sectional area equal to 5 sq. cm. No changes have been made in the preparation of neat cement briquettes; for normal mortar mixed in proportion of 1 to 3 the old method of mixing the mortar by pounding with a hammer or pounding machine has been superseded by the adoption of plastic mortar, and this adoption is now prescribed in all French specifications. This plastic mortar is mixed with enough water to give it the required consistency to fill the moulds with a simple shaking of the trowel. But in this case the normal sand prepared with two sieves of 60 and 144 meshes must be replaced by another sand of three sizes, called "composed normal sand." To prepare this sand three sieves made of perforated metal sheets are used, one with openings of 0.5 mm., another with openings of 1 mm. and the third with openings of 1.50 mm.

Tests to determine the crushing strength have not yet been incorporated in French specifications, although they are in constant use in several other countries, particularly in Germany and Switzerland. These tests are made upon cubes of neat cement or of normal 1 to 3 mortar and measuring 0.07 m. on the side.

Interesting studies have been made for the purpose of substituting a test determining the resistance to flexure for the tensile test. M. Durand-Claye was among the first to study this question; during the last few years MM. Deval, Feret, and Considère have improved methods very much, and in the near future the test of flexure will probably be finally adopted. It would have the advantage of being made easily and of giving exact figures.

The French Committee on Tests has investigated also the tests of disintegration under action of salt water, and of the determination of the compaction of mortars, their porosity, their effectiveness, etc. The limited length of this paper prevents us from entering into more details in regard to tests which, after all, are only made on special occasions.

Rules have also been framed for testing Pozzuolana, plaster and sands; these rules, however, have not yet been included in any specifications, and these tests are made only on rare occasions. In regard to stones, the usual test is the crushing test, then the gelidity or freezing test, by immersion in a bath at a temperature of—15° cent., the wearing test or resistance to wear and disintegration, etc.

Tests of materials used in construction are far from perfect, as was shown by M. H. Le Chatelier in a recent book;* the majority of tests are made on properties bearing only indirectly on the useful qualities of the materials. The methods of testing are often empirical and based on conventions rather than on exact scientific data.

In order to obtain more precise results it is necessary, therefore, to encourage studies in that direction. Here is a vast field of investigation open to all scientists.

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* "Essais des Produits hydrauliques" (Encyclopédie des Aide-Memorie). Gauthier-Villars, Masson & Cie.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 77.

TESTS OF MATERIALS OF CONSTRUCTION.

TESTS OF CEMENT.

By W. A. Aiken, M. Am. Soc. C. E.

The phenomenally increased production of cement during the past few years, due to the extraordinary demand for the material on account of many varied new applications for construction purposes, and the extension of its use along old lines, has resulted in a demand for more rigid inspection, not only in more elaborate investigation of its physical properties as shown by tests, but markedly, of late, in a close supervision of the process of manufacture never before insisted upon, with the view of reaching more intelligent conclusions from physical laboratory examinations.

This has arisen from the recognition of the fact, that, with all the available records and literature on the subject—which are steadily growing in the files of current engineering papers and magazines and by the work of the cement committees of various technical societies, and the researches of individual specialists—so little is known regarding the chemical composition of cement, that the more thorough the inspection can be made, the more possible will it be to arrive at a just estimate of its true value.

The more one knows of the process of manufacture, the more is it evident that much commercial cement, not equal to the best, will pass the physical requirements of most specifications, which in many cases, while framed with perfect honesty, are so ignorantly drawn, that the manufacturer is confronted with problems, which, if solved with the sole object of meeting stated tests, often produce results at the expense of the purchaser. This condition may be largely avoided by a more intimate supervision of the actual process of manufacture. Hence, the most marked divergence of late from former practice has been the growing tendency to install testing laboratories at the mills, especially in the case of large construction, where special inspecting departments have been organized under the chief engineers of national, state, municipal or private interests. The continued presence of the inspectors involves a more or less elaborate supervision of the material as manufactured; and the more closely this is followed intelligently, the more satisfactory must be the resulting finished product.

Where actual testing is not done at the mill, it is becoming more and more the practice to do the sampling at this point, and these samples, if taken regularly, as should be done, during the actual grinding, and if sufficiently numerous and properly divided to represent a certain quantity of cement stored apart, must necessarily lead, when tested, to a better determination of the product's uniformity, than when samples are taken from packages delivered on the work. This method is also to the advantage of both manufacturer and purchaser as it avoids the vexatious condition arising from the condemnation of material in the field, which delays construction, and is a direct loss in freight from the mills. Any move to insure greater uniformity of product is commendable.

Where, even in the matter of physical tests, the results are so dependent upon the "personal equation" of the tester, as everyone, engaged in this work thoroughly appreciates, it is apparent, on large work divided into sections, that the past and even present-day general practice of testing the material to be used on different sections, under even approximately similar conditions, by different sets of testers, is far from ideal. Even assuming a uniform product, the old method is more than likely to work injustice to the manufacturer, so that the change to one set of operators at a fixed point—preferably that of manufacture, is certainly a long step in the right direction.

The elimination of the "personal equation," as far as possible, has been attempted by the inauguration of a series of meetings, under the auspices of the Cement Committee of the American Society for Testing Materials, attended by representatives of numerous official and private laboratories engaged in cement testing, where a uniform method of manipulation, thoroughly commendable, as recommended by the Special Committee of the American Society of Civil Engineers, was undertaken. Strict rules were laid down for every stage of the operations of tempering and moulding, and careful watch and record kept, with the hope that a satisfactory report could be made from a compilation and comparison of results, leading to the general adoption of the outlined method as standard. But it is questionable, in the writer's opinion, whether the many conditions influencing the results can be controlled sufficiently by this plan to equate results of various tests of the same cement at widely different points. Certainly an examination of tabulated results of meetings thus far held, does not give the encouragement hoped for.

The "personal equation" enters more pronouncedly in neat tests than in sand-mortar tests. A method of "dry briquette" making, now being carried on extensively for the Rapid Transit Railroad Commissioners of the City of New York, for comparison with regularly made briquettes over long periods, gives the writer more hope of eliminating the variation in neat tests than any other plan heretofore proposed. By this method the determination of the necessary percentage of gauge water is done away with, as is the moulding of the tempered paste into briquettes; the variation in weight between individual briquettes as well as the difference in tensile strength is much less than with the ordinary method, while the rapidity with which these briquettes can be made up far exceeds that by ordinary practice and to a still greater degree that by the proposed standard method, which involves the use of the Vicat needle for gauge-water determinations.

Another marked change of late in the matter of cement testing is the growing tendency toward lowering the past high strength requirements at early stages, similar to the history of tensile strength in steel, which has resulted in the adoption of a much lower requirement for that product. The specifications for Contract No. 2, Manhattan—Brooklyn Extension of the New York Rapid Transit Subway, were the first to require prominently a percentage of increase in strength between 7 days and 28 days in both neat and sand tests, which course has been emphasized very recently by the action of the Pennsylvania Railroad in its specifications for the New Jersey—New York Tunnel. The latter limit also the strength of the cement as shown by 7-day tests, so as to conduce more surely to this percentage of gain.

The recent passing to letter-ballot, by the American Society for Testing Materials, of a proposed standard cement specification, wherein the minimum strengths, within limits, at different periods, are given, while not ruling out higher-strength cement, if desired by any engineer, might be interpreted to allow much lower pulling material to be specified than has generally heretofore been called for, marks an advance in the recognition, by the Association of American Portland Cement Manufacturers, of the growing preference among engineers for a product showing less strength at early stages. This product, judging from all the long-time records in existence, most probably will show steady gains in strength over long periods.

The two most marked changes in practice of late in testing cement are:

First.—The recognition that the place to do the testing is at the place of manufacture, which insures more satisfactory sampling and therefore a more uniform quality of accepted material as well as more uniform test results since these are made always by the same operators. This method insures also the additional gain of a complete supervision of the process of manufacture, which, in the light of experience, is certainly a controlling element in a good finished product.

Second.—The marked tendency toward lowering the specification strength requirements in both neat and sand-mortar tests at early periods.

In addition to these the tendency toward requirements for increased fineness in the product may be mentioned. This, in the writer's opinion, will result finally in a specification covering this quality in the raw mix as best solving the question of proper clinkering.

The continued failure to crystallize opinion as to the entire efficiency of any accelerated test for the determination of the quality of soundness should be noted also. Most engineers are still unwilling to waive entirely such requirement, and the lately proposed "standard cement specifications" do contain an accelerated test, less severe than the extreme boiling test, but undoubtedly a concession to its advocates. However, the inspection and testing of cement at the mills, where the product is held for 28-day tests before final action is taken, may relieve some of the friction growing out of the continued insistence on even the severest accelerated test, since, under this condition, certainly no such test need be made until the expiration of 28 days, thus giving the material opportunity to aerate if the tendency toward "unsoundness" when fresh is due solely to the presence of excess of free lime.

Too strong insistence cannot be made for a more thorough study of the changes occurring during the operation of burning cement. The apparent simplicity of its manufacture has tempted many on very slight excuse to enter into its production, and the result is multiplication of mills. The enormously increased output has been absorbed in the vast material development of the United States in late years, and only the future can show it to be of the good quality claimed. The fact remains, that our knowledge of the chemistry of cement leaves much to be learned.

The "queerness" of the material, due entirely to our ignorance of its nature, is undoubtedly the incentive to more rigid specifications and attendant inspection, which yearly covers more and goes beyond the mere matter of testing. The sooner the manufacturers take up this question, after the practice of certain large steelmasters, the better will be the quality of commercial cement. At many steel mills dozens of patient students, whose special duties and lines of work, few, save the inner management know, have been on duty. The aggregate value of the conclusions of these men, based on their observations of practice and experiments in theory, is worth many thousand times their salaries.

Testing is not inspection, no matter how conscientiously and expertly this latter is done, and the place for inspection is at the place of manufacture, as is being gradually realized.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

TESTS OF CEMENT.

By Messrs. James E. Howard, F. Schüle, L. J. Le Conte,
J. A. Fairleigh, Frederic P. Stearns, Richard L. Humphrey,
Edouard Candlot and W. A. Aiken.

Mr. Howard. James E. Howard, Esq., Watertown, Mass. (By letter.)—At the Louisiana Purchase Exposition, there was exhibited a sample of neat Portland cement from the testing laboratory of the Watertown Arsenal, which had a crushing strength of 19 120 lb. per sq. in. at the age of one month; and also, a cylindrical specimen gauged with 5% of water. A diagram on the temperatures acquired by 12-in. cubes of cement while setting, which attain a temperature above 100° cent., as well as a diagram on the strength of cement exposed to a temperature of zero fahr., and at subsequent intervals to 70° fahr., were also shown.

Mr. Schüle. F. Schüle, Esq., Zurich, Switzerland.—In the methods proposed for the testing of cement in the United States there is much that is analogous to the methods used on the European Continent. The greatest differences appear in the required strength of cement. American specifications fix only the tensile strength for pure cement and cement mortar. Germany and Switzerland have abandoned the test of pure cement for the normal test, this test having no practical value. Cement mortar, 1:3, is tested not only for the tensile strength, but also for the compressive or crushing strength. Experience has proved that the compression test is more reliable than the tensile test, and for tests covering a series of years, the

Mr. Schüle. compression test only gives useful results. The tensile test is sufficient for current testing of cement, but as tests of concrete are made by compression, it is useful to have, for comparison, similar tests of cement mortar.

It is important to attain the same degree of compression in the test pieces for tension and compression; this result is obtained by ramming (*pilonnage*) the mortar with the same mechanical work used for each gramme of the dry mixture. Another method has been indicated by M. R. Féret in using prisms at first in the bending test and then making the compression test with the pieces of the broken prism. The tensile strength of the calculated bending strength can be obtained by dividing the latter by 1.9 or 2.

Mr. Le Conte. L. J. Le Conte, M. Am. Soc. C. E., Oakland, Cal. (By letter.)—All the old standard cement works are compelled to employ a competent laboratory force, whose duty it is to test the raw material as it arrives from the quarries, and, by the results of analysis, to determine exactly what proportion of each ingredient is required in the subsequent mix. There is no other way to determine the proper proportions. Mr. Aiken's paper seems to encroach rather too much upon what he conceives to be the bounden duty of the manufacturers to look out for, if they wish to preserve their good name and maintain the established reputation of their brand of cement.

The practicing engineer's tests should be made on the ground where the construction work is going on. The principal reason for this being that there is no other way of telling what damages the cement may have sustained between the time it left the factory and the time when it was delivered for use on the works. The manufacturer having sold his goods does not care much what these damages may be, but the engineer, who is to use it, does, most emphatically. It is the quality of the cement as he receives it on the works that he is dealing with, and not as it is turned out fresh from the factory. There may be a vast difference, and there nearly always is some difference, depending on circumstances over which neither he nor the manufacturer have necessarily any direct control.

Lowering the specification requirements for strength of neat and sand-mortar tests at early periods is certainly a wise provision, in which every engineer should concur. The high tests demanded in early stages have become quite a serious fad, and the writer is glad to see a reform in this direction. There is, moreover, a very similar tendency toward another fad, which, in some instances, leads to much useless expense, and that is the compulsory use of coarse sand alone. Almost everywhere specifications may be seen which insist upon the use of coarse sand for the mortar as making stronger work. Of course, it makes stronger work in the early stages, but give it time, and the coarse and fine sand mortar will

Mr. Le Conte.

invariably catch up with it. In many localities, it may be practically impossible to get coarse sand alone, and those in charge go to great expense to transport it by rail; whereas they may have an abundance of fine sand, or coarse and fine mixed, cheap and handy, which could be used with perfect safety. By giving coarse and fine sand mortar more time, the full strength and strength equal to that attained by the coarse sand mortar will be secured. As a general rule, after three months' standing, the superiority of strength obtained by the use of coarse sand alone will be all gone. Increased fineness of grinding is highly important, because it enables the engineer to give a much larger dose of sand for a given strength, that is to say, less cement for a given quantity of mortar, which, of course, is an important figure in economy of cost per cubic yard.

Much discussion and lack of harmony seem to prevail as to the efficiency of any accelerated tests for soundness. The writer has never made much use of these tests in practice, but is willing to concede that the tepid-water test is reasonably fair; but the boiling-water test is simply barbarous, and worse than useless, because it rather encourages the use of over-clayed cements which are very undesirable.

Mr. Fairleigh.

J. A. Fairleigh, M. Am. Soc. C. E., Louisville, Ky.—As the speaker understands it, the American Society for Testing Materials is endeavoring to make a standard specification for cement. Portland cement being an artificial product, no doubt a satisfactory standard specification can be made for it. Natural cement being made directly from a great many different kinds of Natural cement rock, the speaker doubts whether it is possible to make a satisfactory standard specification for this class of cement, and, as a matter of general information, would like to know the present status of the matter.

The idea of a standard specification is certainly a good one, the only point is whether it is possible to make a satisfactory one for this particular material. If a committee were to enter at all into the chemical composition of Natural cement, it would be impossible to make a satisfactory specification, as the analyses of Natural cements from different localities vary greatly. As an example, the amount of magnesia varies from 3 to 20 per cent.

If the requirements of the specification were confined to tensile strength, time of setting and soundness, it would probably be practicable to make a satisfactory standard specification. The greatest difficulty would be to fix the time of initial set, which time varies greatly in different cements, and is sometimes regulated by the manufacturer by the introduction of sulphate of lime to the detriment of the quality of cement.

The subject of the relative values of Natural and Portland cement

Mr. Fairleigh. in various forms of construction is an interesting one. It is now pretty well agreed that Portland cement is adapted particularly to reinforced concrete structures, and to all classes of concrete structures where the structure itself is exposed to extreme changes of weather conditions; while, on the other hand, Natural cement is well adapted for use in large masses of concrete in foundations and other unexposed places. In cases where either cement would answer the requirements, it resolves itself into an economic question.

The speaker has frequently been asked the question, "Why does cement set or harden?" and, as he has not been able to answer it very satisfactorily, presents it in the hope of eliciting some definite information. Is the process chemical or mechanical, or both? The subject is a very interesting one, and if there is anyone who really knows why cement sets or hardens, the speaker would be glad to have his opinion.

Mr. Stearns. Frederic P. Stearns, M. Am. Soc. C. E., Boston, Mass.—Mr. Aiken calls attention to and commends the modern practice of testing cement at the mills, while Mr. Le Conte takes exception to this method and thinks the practicing engineer's test should be made on the ground where the work is going on, his principal reason being that there is no other way of telling what damage the cement may have sustained from the time it left the mill to the time of its delivery upon the work.

There seem to be conditions under which both these views may be right. Mr. Le Conte's practice has been on the Pacific Coast, where cement is brought from mills at a great distance, and, under such circumstances, a test on the ground, where the construction is going on, is certainly desirable. There are large works, however, such as those mentioned in Mr. Aiken's paper, and even much smaller works, where testing or sampling at the mill presents many advantages, and it is to some of these, noted during an experience of three years in having cement for a large work sampled at the mill, that the speaker will call attention.

Where cement is sampled after it is received upon the work, and a 28-day test is required, very large storage capacity is necessary in order to prevent delays. The cement has to be handled from cars to storehouses, and there is special liability to delay if any large quantity of cement is rejected.

Where samples are taken at the mill, the cement, when received, is ready for use and, where circumstances permit, may be taken directly from the cars for use in the work, thus saving the expense of handling into storehouses.

Upon the work referred to, samples have been taken of all cement as received, in addition to the samples taken at the mill, and short time tests of the second set of samples have generally been available before using the cement. Longer time tests have also been made in all cases, which have proved that the tests of samples taken at the mill could be trusted to show the quality of the cement as received upon the work. Mr. Stearns.

Most engineers have experienced the difficulty of keeping a sufficient supply of cement on hand at all times to permit 28-day tests to be made. In the work referred to, the time of transit from the mill to the work was usually from one to two weeks, and the 28-day test was usually available before the cement went into the work, even in cases where it was necessary to ship the cement in advance of the completion of such tests.

It is, of course, obvious that, if a large number of purchasers had separate organizations for sampling or testing cement at the mill and required that it should remain in bins for 28 days before being shipped, the number of bins required for storage might be a source of trouble and expense to the manufacturer. The purchaser can, however, afford to pay enough more for cement which has been stored and tested to offset the extra expense to the manufacturer. Separate organizations for sampling and testing for all purchasers are not necessary.

Except where the distance from the mill to the works is so great that the quality of the cement is likely to change during its transportation, the policy of testing or sampling at the mill is to be commended, and it will result, as Mr. Aiken has stated, in the avoidance of "the vexatious condition arising from the condemnation of material in the field, which delays construction" and causes loss to both manufacturer and purchaser.

The suggestion has been made in one of the discussions that there is an unnecessary discrimination against fine sand in the preparation of mortar, and that mortar made with it becomes in time about as strong as that made with coarse sand. There may be cases where fine sand will give sufficiently good results, but many tests made upon the works, upon which the speaker is engaged, show that mortar made with very fine clean sand, or with a large proportion of the very fine sand, was less dense, more permeable and weaker at all periods from fourteen days to three months than mortar made with coarse sand. The mortar for these experiments was mixed in the proportion of 1 part of Portland cement to 2, 3 and 4 parts of sand, and 1 part of Natural cement to 1 and 2 parts of sand.

Mr. Humphrey. RICHARD L. HUMPHREY, M. AM. SOC. C. E., Philadelphia, Pa.— Concerning the falling off in tensile strength of briquettes of Portland cement, after long periods of time, the speaker would remark that this is a phenomenon for which our system of testing is at fault.

When we take an intimate mixture of calcareous and argil-

Mr. Humphrey laceous materials, burn it to a clinker, and reduce this clinker to an impalpable powder, we obtain an anhydrous, unstable compound, which becomes stable only by hydration. This hydrated compound is an artificial stone, which has been produced in a very short time, and which Nature would require centuries to produce on a larger scale. This hydration or crystallization begins with the addition of water, and it is doubtful whether it ever ceases. If a piece of hardened cement is reduced to a powder, it will still have the power, when mixed with water, of hydrating, and very gradually acquiring strength. As the hydration ceases, the mass becomes more crystalline, and, therefore, more brittle. With the present perfection in the process of manufacture this condition is attained very quickly.

In the rotary-kiln process of the present time, the extremely fine pulverization of the raw material and finished product, and the uniform conditions under which the burning takes place, produce a Portland cement, which crystallizes with great rapidity upon the addition of water. While the vertical or fixed kilns yield a less perfect product, one in which there is a smaller percentage of anhydrous compounds, and one which acquires strength slowly, nevertheless it eventually attains the strength of the present Portland cement.

The thoroughly hardened material is a rock or artificial stone, we do not test stone in tension; why then should we test cement in tension? In the design of concrete structures, we disregard any tensile strength which the concrete may possess, and consider its compressive strength only, adding sufficient metal to carry the tensile stresses. In testing cement in tension, we are testing it under conditions in which we do not use it. Cement tested in compression generally shows progressive increase in strength with age.

Again, in order to render the freshly manufactured product commercially available, it is necessary to season it artificially by the addition of sulphate of lime in the form of gypsum or plaster. This produces compounds of lime, which augment the tensile strength, but which decompose in the formation of more stable compounds, and to this is also due the apparent loss of strength.

The methods of testing cement are largely the result of custom. The tensile testing machine is cheap and can be purchased for from $150 to $200, a sum well within the means of the average engineer, who wishes to equip a testing laboratory. Machines for making compression tests are much more expensive, the price ranging from $500 to $900. The usual compression machine requires power to operate it.

In the model laboratory of the Association of American Portland Cement Manufacturers is a 40 000 compression machine, hand-driven and quite compact. This machine was especially designed

Mr. Humphrey. for the laboratory and to meet this condition. It can be purchased for $300, and it is hoped that this fact will tend to stimulate the more general use of the compression test.

The use of dry mixtures to which Mr. Aiken alludes is not new, the method having been used in England some time since, its use by the New York Rapid Transit Commission being a recent revival. The speaker has had considerable experience with this method and has found that no more uniform results have been obtained by different operators than those obtained by the plastic paste method recommended by the Special Committee of the American Society of Civil Engineers on Uniform Tests of Cement. Indeed the same operator has much greater variation in his results; this was true in a laboratory where the method had been in use for a very considerable time. The method requires considerable skill and practice before satisfactory results can be obtained. Besides it cannot be used for sand mortars, the most important of the strength tests. As it would not be desirable to use one method for the neat test and another for the sand test, the method is hardly likely to be considered seriously in any scheme of testing.

With reference to the results of the tests made under the direction of the Committee on Standard Specifications for Cements and the results of the laboratory meetings of the Special Committee on Uniform Tests of Cement, to which Mr. Aiken refers, and concerning the value of which he appears inclined to be skeptical, the speaker would remark that when a method is used for the first time, no matter what its merits may be, the results can hardly be expected to be concordant until the operator has acquired some skill and familiarity, through usage. The first results are necessarily erratic. So it was with the results of the experiments made under the direction of these committees. Most of the operators had never used the methods before. The results were, under the circumstances, surprisingly concordant; in a number of cases, the operator obtained more uniform results than he could with his own methods. It is safe to say that after a trial for an equal number of years, the present methods of the Special Committee of American Society of Civil Engineers will yield uniform and comparable results. Certain it is that these methods are more readily understood and more quickly interpreted than was the case with former ones.

It is unfortunate that, with any method, experience is requisite for successful results. It is noticeable that two persons beginning to test cement for the first time, under identical conditions and methods, obtain non-concordant and erratic results until they become skilled, and even then they do not agree, the variation being due to the personal equation. This personal equation is made up of a number of variables. Some men are more clever than others, Mr. Humphrey. some are of phlegmatic and others of nervous temperaments, which affect the results of their work from day to day and even during the same day. Mechanical devices offer the most logical field for the solution of this troublesome question, although thus far, no mechanical device has been suggested, which will yield as uniform or satisfactory results as the hand method.

There are certain objections to making the test at the mill in the manner proposed by Mr. Aiken. In the first place, if the cement is to be held in bins awaiting 7 or 28-day tests, before it can be shipped, it would mean the holding of large quantities of cement in stock. If there were but one or two customers requiring this storage, it might not matter so much, especially if they were large consumers; but suppose every consumer would insist on this method of inspection, then it would become a serious problem for the manufacturer and impractical of execution, save by the shipment of cement from a bin to several customers on the test of a single person. Such a plan would be open to very serious objections. Aside from this, cement is such an unstable compound that the logical place to test it would be on the work in which it is to be used. For cement, unlike a bar of steel, does not stay tested, but is constantly undergoing changes which tend to impair its quality.

As to the chemical composition of cement, the speaker feels that he would be a wise man indeed who could prescribe a composition that would be applicable to all classes of raw materials.

The raw materials in use in the United States are so diversified in character that the composition of the finished product will vary with each class. The preparation of the raw materials also varies. With those of the Lehigh District, it is not necessary to grind nearly as finely as in the case of a pure clay and limestone. In the latter case, it is absolutely necessary to reduce the raw mixture to a much finer state. The percentage of lime in the mixture also varies with the character of the raw material, and it would be impossible, therefore, to lay down a standard mixture and method of treatment for each mill.

To attempt to control the chemical composition of the finished product would be the height of folly in the present state of this art. All we can do and all that is necessary is to limit those ingredients which are believed to be objectionable when present in excessive proportions.

Considering the question of long-time tests and the value of the rotary-kiln cement as compared with the vertical or dome-kiln cement, the speaker would state that, when he first began testing cement in 1892, all cement was burned in set or vertical kilns both in the United States and abroad. The cement burned in this way was not as perfectly prepared as it is to-day; the material, being a mixture of active and inactive particles, acquired strength very slowly and attained considerable strength only after a number of years, the curve of strength being a constantly increasing one. This is why long-time tests showed up to such good advantage. With Natural cements, which were but little inferior to the earlier Portland cement, the growth was even more marked. This class of material was practically a sand cement, being a mixture of burned and partially burned rock. The acquirement of strength was, however, very much slower than in the case of Portland cement. The mass was much tougher, and took years even to approach the brittleness of Portland cement. If we could afford to wait for Natural cement to acquire strength, it would make an admirable material. In most constructions, we are obliged to remove the forms in 24 or 48 hours, an interval entirely insufficient for Natural cement, which requires from 4 to 6 months to develop any considerable strength. The Portland cement manufactured at the present time acquires enough strength in from 24 to 48 hours to support the full load. The process of manufacture is such as to admit of rapid crystallization, which renders it exceedingly brittle, in which condition it shows gradually decreasing tensile strength and increasing compressive strength. **Mr. Humphrey.**

The earlier Portland and Natural cements were mixtures of cement and raw rock corresponding to the cements in use abroad known as sand cements. The product hardens into a tougher, less brittle mass, and the speaker thinks we will eventually come to use sand cements in this country, as they are more economical. Our present mixtures are too rich, that is, the cement is too good for the purpose and needs dilution. Structures built of sand cement are tougher, develop fewer cracks, and are far more satisfactory.

Replying to Mr. Fairleigh, the speaker would state that it is matter of indifference to the engineer as to the material from which the cement is made, so long as it meets certain requirements as to fineness, tensile strength, time of setting, and remains constant in volume. Both Natural and Portland cements have their uses, the former having some serious limitations; it cannot be used in concrete constructions, where the whole load must be carried in 48 hours. If the engineer requires a concrete base for a pavement, or backing for a retaining wall, he does not need the strength developed by Portland cement, as Natural cement would be sufficiently strong.

The Committee on Standard Specifications for Cements has formulated requirements for each, both Portland and Natural cements, covering the fineness, the specific gravity, time of setting, tensile strength, neat and with standard sand, and constancy of volume. The Committee has not prescribed chemical requirements,

Mr. Humphrey. because it did not deem it necessary for Natural cements, and for Portland cements, it limited the allowable percentage of SO_3 and MgO, which are generally considered dangerous when present in excess.

Answering Mr. Fairleigh's question as to why cement sets or hardens, it may be said that it has been pretty well established through the microscopical investigations of Le Chatelier and others that the phenomenon of hardening is purely a chemical one and is the result of the mechanical intermeshing of the crystals of silicate of lime, etc., which are formed by the hydration of the cement powder.

The cement resulting from the pulverization of the clinkered raw materials is anhydrous. Upon the addition of water, it begins immediately to hydrate in the form of fine needle-like crystals, and it is the intermeshing of these crystals that produces the hardening. They can be seen forming under a microscope immediately upon the addition of water to cement. The action is analogous to the formation of crystals from a saturated salt solution. If water is added to a cement that has commenced to set, and it is again mixed, the crystals already formed will be broken up, and the mass is weakened by this retempering. Successive repetitions will gradually destroy all bond, and the cement having set or crystallized, the mass will become like so much inert sand.

The percentage of fine silt or dust in sand, the speaker believes to be of great importance. In the discussion of Concrete and Concrete-Steel before this Congress, he had occasion to refer to the incorrect use of the term, "loam." It has been stated in a number of recent papers that loam up to 15% might be considered harmless. In the generally accepted meaning, loam refers to finely disintegrated material.

A graded sand makes a much stronger mortar than sand screened to one size. The variation in the percentage of voids is quite a factor, a crushed-quartz sand may vary from 35 to 50%, while a round-grain sand will, as a rule, contain a lesser percentage of voids. Sands of this character will pack more closely, especially if the finer particles are not screened out. Such sands require a minimum quantity of cement to produce a mortar of given strength. The percentage of fine dust should be just sufficient to fill the voids and any in excess of this amount weakens the mortar or concrete.

The present standard sand consists of a single-size grain. The French standard is a mixture of three sizes; it is difficult to secure uniform sand with grains of several sizes. A 20-40 sand gives higher values than 20-30, but the difficulty lies in the variation in the size of the grains between these limits. While a 20-30 sand gives relatively lower results than a graded sand, it is more easy to obtain a uniform sand of that size. It is possible to obtain two different sands of the 20-30 size that are comparable. This is not the case with two sands screened to 20-40 or 20-50 size. **Mr. Humphrey.**

Mr. Candlot. EDOUARD CANDLOT, ESQ., Paris, France. (By letter.)—Mr. Schüle says that, in Germany and Switzerland, neat tests of cement have been abandoned because such tests have no value. This is not the writer's understanding; on the contrary, he thinks that neat tests give a much more exact idea of the value of a cement than normal sand tests.

In the first place, the variations of strength between cements of different quality are greater with neat cement than with 1 to 3 mortar; a cement, for example, will give 40 kg. per sq. cm. after 7 days with neat cement, and 20 kg. with 1 to 3 mortar; another very finely ground cement will give only 30 kg. with neat briquettes and 15 to 18 kg. with 1 to 3 mortar. This fact is very easily established by comparing well calcined with lightly burned cements; the former showing much greater strength in neat tests, while the latter have a strength, with sand, often as great and sometimes greater.

In the second place, sand tests are often difficult to make because good sand is not always easy to procure; the normal sand of one country differs from that of another, and the results do not agree. Moreover, the mortar briquettes are not so easily manufactured as the neat cement briquettes.

The only argument which can be advanced in favor of the use of normal mortar is that tests made with it resemble conditions in practice. This is a fallacy, however, because, in practice, mortar is made in an entirely different manner, the sand is not the same, the conditions of its use are very different, etc.

The writer, therefore, believes that it would be a great error to do away with neat tests. In France, in all specifications, these tests have been retained, and it is to be hoped that they will also be retained in America.

Mr. Aiken. W. A. AIKEN, M. AM. SOC. C. E., Pittsburg, Pa. (By letter.)—There is no question but that the most rational way to test cement, either as neat paste or sand mortar, is under compression, this method most closely approximating actual service conditions. The reason for the general failure to adopt this method has been due only in part to custom and the cost of apparatus, much more, in the writer's opinion, being due to the fact that such apparatus, as heretofore manufactured, were not sufficiently portable for field use. Undoubtedly, with the improvements in these machines and their lowered cost, their adoption in permanent laboratories which, as the paper states, are becoming the vogue, is only a question of a short time, since, in spite of criticism, the place to inspect and test

Mr. Aiken. cement is rapidly being acknowledged to be the point of manufacture.

Normal products will not change sufficiently under ordinary conditions of shipment, to impair the quality materially, and the question of storage room at the mills must be met like any other commercial question. If this requirement is demanded by the purchaser, in order to ensure a record of his material before use, the manufacturer who meets this demand will certainly get the business.

While Mr. Humphrey failed, in such experience as he has had, to obtain any more uniform results with a "dry" method of briquette making than with "wet" mixtures, the fact remains that the elimination of the "personal equation" is a desideratum. The "dry" method referred to by the writer as being used, corroboratively only, on the New York Rapid Transit work, does eliminate very largely this variable quantity, as shown by results of tests far in excess, numerically, of any on record on any previous piece of construction, and while, as correctly stated by Mr. Humphrey, the "dry" method is applicable to sand-mortar testing, undoubtedly the most important point in determining the value of a cement, the writer cannot see, if neat tests are to be continued, what valid objection can be urged against the use of different methods for neat and sand tests, providing experience and the accumulation of data, which are after all more conclusive than this or that man's opinion, prove the "dry" method superior for neat tests, wherein the personal equation enters more largely than in sand-mortar tests. The dissertation on the chemical constitution and manufacture of cement, while a thoroughly interesting one to the writer, has introduced into this discussion a subject entirely foreign to the scope of the original paper, *viz.*, the testing of cement. Therefore, no comment thereon is considered necessary.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 78.

TESTS OF MATERIALS OF CONSTRUCTION.

TESTS OF STEEL.

By L. Baclé.*

Translated from the French by
Paul A. Seurot, M. Am. Soc. C. E.

The results of constant study of questions pertaining to the testing of metals in France during the past ten years have been followed with great interest in other countries as they seemed to be the forerunners of radical changes in the usual practice of testing.

They have shown, on the one hand, the possibility of obtaining, in more satisfactory conditions, the characteristics which are always objects of investigation in all usual tests, such as the elastic limit, the maximum breaking load and the elongation considered as a means of measuring ductility.

On the other hand, these researches have also caused a thorough discussion of the usual methods, the authority of which had never been doubted until then; such, for instance, as tension, and proved after all that these methods could well be criticised, that they were unable, for instance, to give any certain data on as important a property as brittleness; they showed that it was necessary to seek new testing methods for the study of this property, and also to bring forth the qualities of homogeneity of the tested sample.

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* Ingénieur Civil.

French experimenters have successively studied these two essential questions and found very satisfactory results, as will be shown in the following *résumé.*

The first experiments so conducted were made at the request of the official Commission appointed in 1891 by the Minister of Public Works with the object of standardizing these methods, which in practice showed divergences so great as to divest the results of any comparative value. It was observed that the types of the samples, the mode of setting the heads, the apparatus recording the stresses, or the resultant elongations, even the conditions and mode of procedure of the test had a decided influence on the results, and thereby tended to alter them greatly one way or another. It was, therefore, necessary to operate in a standard uniform way to avoid such differences.

The Commission having then, as its duty, the formulation of the best methods and best conditions to be adopted in practice, scrutinized all the known testing methods and made a complete study, the results of which are condensed in the general report submitted in its behalf in 1893 by MM. Baclé and Debray, which was the starting point of all the experiments and researches which are described farther on.

The first researches made by the Commission tended in a great measure to impeach the accuracy of the usual methods by showing that the results obtained by them are too often irregular, that they do not always show properties eminently characteristic of the metal, and that, too frequently, they do not warrant the necessary expenditure of time and money.

The experimenters then studied successively the adoption of means to improve the installation of the testing apparatus, to utilize usual shop practice and operations, to formulate new methods of recording the usual data, and finally they recognized, little by little, that it was impossible to test brittleness by known methods, and, therefore, it was necessary to adopt new methods.

When the researches of the Commission were interrupted in 1900, it was prepared to outline, in its second general report, the principle of these new methods, the study of which has been successfully pursued since that time with marked success by skilful and conscientious experimenters.

The bulk of their work has been condensed in the papers published by the French Section of the International Association for Testing Materials, and was submitted to the International Congress held at Paris in 1900, and to the following Congress held by the International Association at Buda-Pesth in 1902.

These papers were printed in a volume published under the auspices of the "Société d'Encouragement pour l'Industrie Nationale," which can be consulted by the readers, as well as in the proceedings of the French Commission and of the two Congresses mentioned above. Only a short *résumé* will be given here.

Improvements Made in Recording Results.

The object in view was to get diagrams giving a permanent curve of the different stages, and pointing out at once the principal characteristics of the test, such as resistance and elongation in the tensile test.

Apparatus more or less precise was used; nothing special can be said about it other than that it proved its efficiency by certain ingenious arrangements, without bringing out any new principle.

The apparatus invented by M. Frémont, called Elasticimeter, will, however, be mentioned. This device makes use of the flexures of the structure itself to determine the stresses which are thus automatically recorded without any other intermediate agency.

The elasticimeter was used by M. Frémont in all testing machines recording graduating action such as tension, flexure, compression, as well as punching and shearing, and it always gave a clear and accurate diagram far superior to any ever recorded with more complicated apparatus.

As has been seen, tests, as a rule, show chiefly the resistance or tenacity and the total elongation of which the metal is capable, but they rarely show with any degree of accuracy the important property known as elastic limit.

Diagrams, of course, give some vague indication of the elastic limit in the bend which is usually seen in a curve representing the elongation, but very often it is impossible to fix that limit with any certainty, and the tendency is to give it a different value according to the conditions of the test and the aim in view.

It is thus that the Commission came to consider three distinct limits:

A proportional elastic limit characterized by a stress beyond which the elongations do not increase proportionately to the forces or strains; an apparent limit characterized by a determined stress which remains constant notwithstanding the fact that the elongations increase; and finally the theoretical limit which is characterized by the maximum stress which can be applied to the sample without causing a permanent set.

When a determination of this theoretical stress was attempted, with improved apparatus capable of recording elongations as small as one-thousandth of a millimetre, it was evident that within such small limits it was almost impossible not to get a permanent set; it may be said, in truth, that in such conditions the elastic limit disappears or gets away from the experimenter, who might be led to think that there was no elastic limit, if practice did not show him that such is not the case.

It becomes necessary, then, to adopt new methods to determine this elastic limit, and M. Frémont has successfully given an explanation of this anomaly, and has devised a new method to obtain a solution.

He showed that permanent sets, which are recorded by accurate apparatus, are only local deformations, and are probably due to the fact that the applied stress does not take effect immediately upon the whole sample or piece. To determine the elastic limit, M. Frémont proposes to use a sample, conical in shape, short and carefully polished.

When such a sample or bar is pulled under a tensile stress the metal gradually loses its polish along a portion continually increasing as the stress increases, and this change in the appearance of the metal indicates all the points or parts where the elastic limit has been either reached or passed. Rupture takes place at the weakest point under a total stress corresponding to the resistance of the metal at that point, but this total stress measures at the same time the elastic strain applied upon the enlarged section forming the depolished or tarnished portion of the sample.

M. Frémont's method, as is seen, gives directly the elastic limit and the breaking load; it also has the additional advantage of furnishing a characteristic element of great value which the usual tension diagrams do not give in such a satisfactory way, and that is the elongation of striature which appears immediately on M. Frémont's test-piece, since the rupture necessarily takes place at the reduced section left purposely in the sample.

In the usual practice, is recorded under the name of total elongation, an uncertain quantity which is the sum of two elements entirely different in nature and value: the distributed elongation and the elongation of striature.

The distributed elongation is simply the sum of all the elementary elongations due to imperfect striæ which have started during the test on various parts of the sample and before the final localization which must cause rupture.

These elementary or partial elongations, which cause the formation of these curious striæ known as Luders' Lines, do not seem to follow any precise rule, and take place in a somewhat haphazard fashion, and are not, therefore, a characteristic of the metal.

Experiments show that the measure thus recorded presents great discrepancies and differences in all tests made upon samples of usual manufacture, even on samples of good quality, and if in a breaking test the differences are already 10% above or below, they reach values two or three times greater in distributed elongation.

It will be understood at once that an element so irregular cannot be considered as measuring a real characteristic of the metal, while it is quite a different thing with the striature; and all the experiments recently made have shown conclusively the necessity of distinguishing it from the distributed elongation; but unfortunately the distinction between the two is very hard to make with any degree of accuracy when the tensile tests are made on the usual samples; and this consideration will, in the future, probably lead the experimenters to change the usual type of test-pieces and to adopt other test-bars somewhat similar to those used by M. Frémont.

French experimenters have not only made a study of tensile tests, but have also studied two other interesting methods of testing which must be mentioned here. One consists in determining the mark or impression obtained in the test of superficial penetration with a knife having a pyramidal shape. This test was made before the Official Commision by Colonel Martel. The other is the shearing and punching test made by MM. Baclé and Frémont.

The test of penetration by the fall of a pyramidal knife permits the determination of the resistance of the metal; with a knife having a given shape, falling from a known height, a mark or impression, the depth of which varies with the nature of the metal, is obtained, and for different known metals it is found that this depth is proportional to the resistance to rupture as measured in the tensile test.

This ingenious method is very similar to the one which was devised in Sweden by M. Brinell, and which consists in measuring the superficial impression on a steel billet under pressure; it has the advantage of giving precise information as to the resistance of the metal by allowing the test to be made upon the piece itself upon all points of its surface without the trouble of securing a special sample.

Tests made by punching or shearing are particularly interesting because they may be made in the shop and secure immediate results that a tensile test would give only after a costly operation necessitating the cutting of a special test-bar. This method is based on the reading of a diagram obtained with M. Frémont's elasticimeter. In a study of this diagram made by MM. Baclé and Frémont, it is shown that it gives directly, by its maximum ordinate, the value of the resistance to rupture, and probably the elongation of striature.

New Methods of Determining Brittleness.

The methods which have been mentioned determine usual characteristics; but researches made during these past ten years have shown, as has been said already, that these characteristics are insufficient, at least generally, as long as they do not give any information on brittleness.

French experimenters have tried to demonstrate this property by a new method of testing, and they have done in this respect some very interesting work. The names of all those who have studied this question cannot be given here. MM. A. Le Chatelier and Barba were the first to point out the advantage gained in using notched test samples; they showed that the intervention of the notch, by localizing the rupture, finds, so to speak, the metal in its inner condition, keeping it from deformation during the test, as is always the case in tests with graduated action, and, effectively, the experiment has shown that the test of notched bars gives results which show well the brittleness of the metal. All the experimenters have recommended the test by a blow on the notch, but they have not yet succeeded in reaching unanimous conclusions as to the best conditions to be adopted for the execution of the test, nor as to the shape to give to the notch.

Some, like MM. Barba and Le Blant recommend an angular, V-shaped notch, of which, unfortunately, it is not always easy to maintain the shape. Others, like M. Charpy, recommend a circular notch, perfectly geometrical, which is always identical, but unfortunately requires a great thickness of metal.

Others, too, like M. Frémont, are content with a simple saw-notch, measuring from 1 to 3 mm. in depth. M. Perot, Director of the Conservatoire Laboratory of Tests, proposes a wide notch spread on a width of from 2 to 3 cm.

The same differences are found in the arrangement of the drop-hammers; but it must be said that, generally, the experimenters are trying chiefly to measure the energy spent in the rupture of the test-piece directly, and this gives better and more precise results than the old methods. Knowing the total energy stored in the hammer at the time of the blow, it is, evidently, only necessary to measure what energy remains after rupture in order to deduce, by the difference, the energy effectively spent in the work of the rupture.

To do so, M. Frémont puts a little below the test-bar a spring or crusher, which is struck by the hammer after it (the hammer) has broken the test-bar, and the compression of the spring or crusher measures immediately the unspent energy; whence is deduced the spent energy. M. Charpy in his experiments uses a pendulum, which is guided, and meets the test-bar to be broken at the bottom of its descending course, ascending again to a point more or less high, according as the work of rupture has required a greater or smaller quantity of disposable stored energy. M. Guillery has designed a rotary hammer, based on the same principle as the drop-hammer of M. Frémont, which, in practice, gives equally satisfactory results.

The ingenious arrangement designed by M. Perot which enabled him to obtain a perfect diagram of the drop test or shock should also be mentioned.

He uses a drop-hammer furnished with a photographic plate. This strikes the test-piece, which is itself attached to a movable articulated anvil, the motions of which are counterbalanced by a spring. A ray of light coming from a fixed source is reflected by a mirror fixed on the axis of the anvil, which in its rotary motion, gives to it a certain deviation that is recorded on the photographic plate attached to the hammer. A diagram varying with the conditions of the rupture is obtained on the plate, and it is then possible to get an idea of the phenomenon and of the principal circumstances that have followed, notwithstanding its almost instantaneous duration.

M. Perot's ingenious apparatus, of which the principle can merely be mentioned at present, will undoubtedly give, in the future, experimental data to throw some light on this difficult study of the phenomena due to blows, and it is particularly fitting to mention here the learned studies which have been pursued in this direction during the past ten years by French experimenters.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 79.

TESTS OF MATERIALS OF CONSTRUCTION.

TESTS OF STEEL.

By William R. Webster, M. Am. Soc. C. E.

The results of physical tests of steel are so dependent upon the heat treatment it has received in manufacture, and on its chemical constitution, that one can hardly be considered without the others. Formerly, it was thought that if steel was low in phosphorus and other injurious elements, it could be relied on to give satisfactory material when rolled into plates, bars, shapes, etc. But it was soon found that the temperature at which it was finished in rolling had as much, if not more, influence on its physical properties than the small differences in the chemical composition of the steel met with in practice. The trouble referred to is much greater in thick material, and increases as the amount of carbon is raised.

It was also found that some material giving good results in the tension tests, failed when subjected to the bending test, some pieces closing down flat without cracking and others breaking off short with granular fracture. Further investigation showed that steel finished too hot in rolling will have a large granular structure, but, under the slow pulling action of the testing machine, it may give a good elongation. This is very misleading, as, when subjected to the bending test, it breaks off short, showing that the material is brittle.

This matter is of much more importance than at first appears, and has led to failures of material in the shop after much work has been put on it, the trouble being caused in most cases by accepting the material on the results of the tension tests alone and not making any cold bends. This has brought about a reaction, and now the bending test is coming more into favor every day, and should never be omitted, as it is one of the best tests in use to detect brittle steel.

In many specifications the requirements for bending test call for steel to bend a given number of degrees before or after it is heated to a dark cherry red, and quenched in water; this quench bend being considered by many to be much more severe than the ordinary cold bend. In some cases where both are specified, the cold bends have been omitted. This has also led to trouble, as the quench bend of medium or soft steel is the most unreliable test we have. Material that is brittle and will not give satisfactory results in the ordinary cold bending test will often bend down flat after it has been heated and quenched in water, the explanation being very simple. The heating anneals the steel, and the carbon in it is not high enough to harden by subsequent quenching. Quench bends will not only pass material that would not stand bending cold in the condition in which it was rolled, but they give very misleading results as to the injurious effects of shearing. If pieces of plates or angles with sheared edges are heated to redness, the compressed and hardened edges are restored by the heat, that is, annealed, and the subsequent quenching does not again harden the steel. These are simple facts, well understood by shop men, but are often overlooked by the engineer. This is not to be wondered at, as it is only in recent years that we have understood the changes produced in the structure of steel and the reasons for such changes.

It was not until the series of papers on the Physics of Steel read before the Mining Section of the International Engineering Congress, Chicago, 1893, which was in charge of the American Institute of Mining Engineers, that any systematic attempt was made to locate the cause of the troubles met with in steel and find a remedy for them. Suggested lines for discussion and investigation were prepared, and the discussion extended over several years before that Institute. This was productive of much good in bringing home to engineers and manufacturers many matters, overlooked or unknown, that had an important bearing on the character of the finished steel—the most important of all being the changes in the structure by heat treatment in its manufacture. It was shown that good steel could be rendered worthless by being finished too hot in rolling or forging.

Microscopical examinations of steel have been of the greatest assistance in this work, as they have shown the critical points in steel, and that slight changes in temperature at which steel is worked are of much more importance than formerly admitted. Persistent investigation in this and other lines of research, has resulted in a much better understanding of how to produce good steel for structural purposes, and how to detect defective and unreliable steel, and to prevent its getting into service.

Similar work by the British Iron and Steel Institute has assisted materially in clearing up the whole situation. The papers of Mr. C. H. Ridsdale on "The Correct Treatment of Steel"—1901, and "Diseases of Steel"—1903, in which he makes a strong plea for an acknowledged system of investigation, may be instanced. His numerous tables and charts are well worthy of study by all engineers interested in this subject.

The papers of Messrs. J. E. Stead and Arthur W. Richards on "Sorbitic Steel Rails" and "The Restoration of Dangerously Crystalline Steel by Heat Treatment," are of the greatest importance, they have shown that by simple heat treatment, a very much tougher rail can be produced, than those made under the ordinary conditions of manufacture. These papers were discussed jointly with that on the "Diseases of Steel," and brought out much additional matter of interest. The subjects are of so much importance that the discussion will no doubt be continued.

The American Society for Testing Materials (affiliated with the International Association for Testing Materials) has drawn up specifications for different classes of steel. In all cases their committees were large and manufacturers and engineers were equally represented. It was the object of the committee to hear both sides of all questions before deciding on any requirement or test.

Their specifications have been discussed by leading engineering societies of this country and committees appointed to confer with them. The work is still going on and will no doubt result in standard specifications that will come into general use in the next few years. Their work may be regarded as that of a clearing-house in getting rid of a lot of worthless matter in the specifications formerly in use, the aim being to bring them up to the best modern practice in all respects.

In England the Engineering Standards Committee is doing similar work, under the direction of the Institution of Civil Engineers and the four other leading technical societies. The British Government has recognized the great importance of this work and given its financial support. The War Office and Admiralty Departments, who are among the largest users of iron and steel, are actively co-operating in this work and there are now twenty-four representatives of the Government on the various sub-committees.

The same course has been followed in England as in this country in giving the manufacturers a fair representation on committees. They are taking up the standardization of sections used in ship building, bridges, rolling stock, etc., and standard specifications for bridge material, rails, etc., besides many other subjects.

Professor W. C. Unwin, in November, 1903, read a very instructive paper on "Tensile Tests of Mild Steel; and the Relation of Elongation to the Size of the Test-Bar" before the Institution of Civil Engineers. He gave the results of a large series of tests made for the Engineering Standards Committee on which Committee he represents the International Association for Testing Materials. This paper was very widely discussed and gave the committee much valuable matter for their work. But there were two matters suggested in the paper that can hardly be considered as being disposed of. They are the propriety of omitting from the specifications all chemical requirements, and bending or shop tests.

Some engineers in this country formerly omitted from their specifications the chemical requirements, claiming that if the physical tests were all right it was unnecessary to bother about the amount of phosphorus or other injurious elements in the steel. This might have been all right if the piece of steel tested was the only one under consideration, but as heats of 40 and 50 tons of steel are accepted on the results of a few tests, the engineer must be sure that such tests fairly represent the whole heat. This will never be the case unless the phosphorus and other injurious elements are low to start with, otherwise they will be increased locally by segregation above dangerous limits, rendering the material brittle in spots, and therefore unsafe. To-day all our specifications for bridge material have the chemical requirements as well as the physical.

Enough is known of the effect of the chemical constitution of steel to predict fairly accurately what its physical properties will be under standard conditions of manufacture. This is the best guide the steel manufacturer has, and his whole output is controlled by it. He knows when the results vary widely from those expected, that there is probably some trouble in heating or rolling, and soon corrects it. The engineer now uses both chemical and physical requirements in his specifications with confidence, as he knows better than formerly the relation of one to the other. It is by getting the results expected that we know that suitable steel for the purpose intended has been used to start with, and that it has received the proper treatment in manufacture. To abandon either requirement would be a decided step backward.

There have been no material changes in the methods of testing steel during the past ten years, but the results of the ordinary tests are better interpreted. Recent investigations have more clearly shown changes in the structure of steel produced by heat treatment, and the necessity of making tests which will detect brittleness, as well as tests that will represent the work the material will have to withstand in service. Endurance tests of rotating steel shafts have been carried on for several years by this Government at Watertown Arsenal, and valuable data have been published from time to time on same. About four years ago one of our leading railroads called for vibration tests on stay-bolt iron after it had been threaded. The results of such tests have shown it to be a step in the right direction, and the test is coming into more general use. Formerly the drop test was considered rather crude and likely to give very irregular results, but now it is known that these irregular results were largely caused by improper heat treatment, or poor chemical composition, and that the large grain, due to too-high finishing temperature, is detected by this simple and inexpensive test, and it has come into general use and is much relied on.

In rails the whole question is reduced to the structure of the steel in the head of the rail, which depends directly on the amount of work and finishing temperature in rolling, and our best rail specifications to-day are drawn with particular attention to the heat treatment. High finishing temperature gives a large grain in the head of the rail, this in turn gives a poor wearing rail, and one that will fail under the drop test. To keep such rails from being put in service, the upper limit of finishing temperature in rolling is specified as well as the maximum amount of shrinkage allowed in rails at the hot saws; the height of fall of drop has also been increased in the heavy rails which are more liable to be injured by a too-high finishing temperature. On the other hand, rails finished at a low temperature will have a fine grain in the head, will give good service, and will not fail under the drop test.

Engineers and manufacturers are endeavoring to get a finer grain and tougher steel in the head of the heavier rails. Delayed rolling in order to finish the head colder has been introduced and other methods have been suggested. The American Society of Civil Engineers has a Special Committee on rails which has been instructed to report on this important matter and on specifications.

Drop tests on rails are more generally required than formerly; in some cases one on each heat, and in others one on each fifth heat rolled.

Most of the old and some present specifications for bridge material contain a provision that when the material is to be annealed, the test piece is to be similarly treated. This is all right for forgings or castings where the test piece is annealed at the same time as the casting or forging, but when it is applied to flats for eye-bars, it is a very different matter, and has led to all sorts of trouble. Bars which had been finished very hot in rolling, and which would have failed under the ordinary tension or bending test, when carefully annealed, met all the requirements specified, and the material was accepted on such tests. The bars after being upset and headed are annealed by methods which can hardly be called perfect. Full-sized tests of eye-bars have shown very different results from those of the small test piece; the bars breaking in the body or the head with little or no reduction of area, poor elongation and granular structure. This trouble increases with the size and thickness of the bar and has been a great drawback to the use of larger eye-bars. This old blanket clause has been one of the most injurious that was ever put in a specification, and only in recent years has it been replaced by one calling for cold bends to be made on the material in the condition it leaves the rolls, *i. e.,* without annealing. Some specifications also call for a tension test of the annealed test piece, others do not call for this, it not being considered necessary.

The general use of very large eye-bars has been made possible by insisting that material should meet the requirements of the cold bending test made on pieces of the full thickness of the bar. In order to meet this requirement it is necessary to put enough work in rolling on the bar at a low temperature to elongate the particles and make a tough steel; otherwise it will fail under this test.

When a very high elastic limit is required on large eye-bars the problem is much more difficult, as the higher carbon in large thick bars, which cool very slowly after rolling, increases the trouble. Under these conditions it is very hard to avoid producing steel with a large grain in rolling, or injuring it in the subsequent heatings for upsetting and forging the heads. Steel containing 3½% of nickel has been tried for eye-bars where an elastic limit of 48 000 lb. per sq. in. was required. Thirty eye-bars were made under ordinary conditions of manufacture and annealing, and tested; the results of these full-sized tests were very satisfactory.

The advantage of steel containing from 3¼ to 3½% of nickel, is that the nickel replaces about 0.15% of carbon and that the material with the same ultimate strength is higher in elastic limit, is much tougher, and is not as easily injured by heat treatment. But of course, where the best results are wanted in any forgings of ordinary carbon or nickel steel, they should be oil-tempered.

The acceptance of steel on the chemical analyses alone has never been advocated, yet some of our railroad companies are doing this on driving axles for locomotives. Others are taking a tensile test of the bloom from which the axle is to be forged; but in both cases the axles are forged and put into service without being annealed, and no physical tests are made of the finished axle. This has been done notwithstanding all that is known of the injurious changes in the structure that may be produced by heat treatment and also that the large mass of metal in a driving axle is much more likely to be injured than that in the small truck axles which are tested under the drop. It is almost incredible that such practice exists with all the information so readily accessible to the manufacturer as well as to the engineer and railroad official.

The different committees at work to-day in this country on the testing of steel and specifications are endeavoring to find better check tests on brittle steel, to prevent its being accepted and put in service. If the discussion at this Congress will treat of this and the other matters directly pertaining to the heat treatment of steel, it will greatly assist in clearing up many of the points at issue.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DSCUSSION ON
TESTS OF STEEL.

By Messrs. Gaetano Lanza, F. Schüle, Sir William H. White, Messrs. A. A. Stevenson and J. P. Snow.

Gaetano Lanza, Esq., Boston, Mass.* (By letter.)—Mr. Webster is doing good service to the engineer and also to the steel manufacturer by emphasizing the importance of including, in the American rules for the inspection and for the acceptance tests of steel, such specifications regarding the finishing temperature as are needed, in order that the product furnished by the manufacturer may stand the test of service. The principal examples cited in the paper are rails and eye-bars; for the former, Mr. Webster urges a shrinkage requirement, and, for the latter, a cold bending test upon material of the entire thickness of the finished eye-bar. It is to be hoped that corresponding requirements will eventually be made for steel which is to be devoted to other uses, as in the case of the usual structural shapes and in that of steel used in the various moving parts of machinery. Prof. Lanza.

In undertaking a study of the requirements needed, whether in regard to the finishing temperature, in regard to the means of securing structurally sound material in the finished piece, or in other respects, we need, as our guide, a far greater number of tests of full-sized pieces of steel, conducted, as nearly as possible, under the conditions of practice, than are now available; such as tests of full-sized bridge columns, plate girders, connecting and parallel rods, cranked axles, etc. It is only natural, in view of the recent

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* Professor of Theoretical and Applied Mechanics, Massachusetts Institute of Technology.

Prof. Lanza. growth in the use of steel, that we should have, thus far, fewer tests of this kind upon pieces made of steel than upon those made of wrought iron, and while it is true that the number is quite small, nevertheless, some such experiments have been performed, and every effort should be put forth to increase their number, as they will furnish the guide to determine what requirements are, and what are not, needed in different branches of service, and they will give to the engineer the knowledge as to what he can depend upon in practice.

Mr. Schüle. F. SCHÜLE, ESQ., Zurich, Switzerland.—Among the new methods of testing steel mentioned by M. Baclé are the impact tests of incised bars and the Brinell test on steel billets, methods which have been the subject of numerous experiments. In Holland and France, tests were made on incised bars in order to study the fragility of steel, and in Sweden on steel billets to obtain a simple and cheap method of determining the quality of a metal. Very important reports as to these experiments will be presented to the Congress of the International Association for Testing Materials in 1905.

The question of testing steel pieces has also been mentioned in these papers. In some cases, it is useful to test larger pieces so as to study the phenomenon of lateral deflection by compression, to verify the strength of forged pieces (eye-bars), or to test the influence of riveting on beams, etc. For the bending test, the laboratories for testing materials have an apparatus for applying a concentrated load upon the middle of the beam, or upon two points of the beam. In most cases, the beams are practically loaded along their whole length. For the past year, in order to test beams loaded along their whole length, the laboratory for testing materials in Zurich has used a machine built by Amsler and Son, of Schaffhausen, where the load is applied at seven points of variable position on the length of the beam by communicating hydraulic cylinders. This machine permits the testing of beams up to a length of 4 m., the maximum load of every cylinder being 18 tons. The cylinders are so disposed that they cannot aid the beams against lateral deflection, as is the case in the machines generally used for bending tests; it is, consequently, possible to study the question of the lateral deflection of beams supported only at the ends. The tests made in Zurich on different sections of both rolled and riveted beams have proved that in symmetrical beams the load in the plane of symmetry produces a lateral deflection independent of the moment of inertia of the beam, in the transverse direction; that this lateral deflection depends only on the quality of the metal; and that it is due to the reaching of the apparent limit of elasticity. Of twelve beams which were tested, only one was suddenly broken at a stress

Mr. Schüle.

equal to the elastic limit of the material; it was a riveted beam with punched holes. The results of these tests have been published by the speaker.* The bending machine is also used for testing concrete-steel beams.

Sir W. H. White.

Sir William H. White, President, M. Inst. C. E., London, England.—These two papers serve the purpose intended by the writers excellently, by bringing into prominence points on which opinions are divided in regard to modes of testing steel, and by endeavoring to suggest uniform tests.

The speaker's experience is connected chiefly with steel used for ship-building purposes and for armour. He conducted the earliest English experiments on mild steel, and since that time (1875) has been interested in the subject. He also had charge, for over 16 years, of all questions affecting the manufacture of armour for British warships.

On one point, the speaker does not agree with Mr. Webster. In all his specifications for steel for shipbuilding, he has embodied the principle that users of steel should have nothing to do with chemical composition; that position he strongly maintains. Continuous experience for thirty years has convinced him that the user only does mischief in specifying particulars of chemical composition. He has known cases where competing firms have fulfilled the requirements satisfactorily with very different chemical compositions of steel, which in working, as well as in tests, showed no difference whatever in behaviour. But freedom for the maker in regard to constituents in the steel has often made a great difference in price. The user has a perfect right to refuse certain modes of manufacture which have produced unsuitable material for his purpose. For example, a careful series of experiments convinced us that, although Bessemer steel was capable of standing all ordinary tests and most shipyard operations as well as Open-Hearth steel, it was not equally trustworthy when riveted work was in question. Consequently we limited the use of Bessemer steel to minor portions of the structure in ships, and used Open-Hearth steel in all important parts. The speaker's observation includes results obtained by working on the other system in England in specifying for steel required for purposes other than shipbuilding, and his conclusion is that mischief has been done by the attempt of users to specify chemical requirements, and that it is preferable for them to specify only mechanical tests.

We ought to be sure that we are getting uniformity in supplies of steel. The prevention of segregation and other faults are matters which the manufacturer should deal with. No manufacturer of good standing would proceed with the manufacture of steel having such faults, or fail to arrange for inspection that would detect them.

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* *Schweizerische Bauzeitung*, 1904.

Sir W. H. White. Since steel armour has been adopted, it has always been the rule of the British Admiralty not to specify the composition, but to require proof that all the armour delivered was identical in chemical composition and mode of manufacture with sample plates that had been subjected to firing tests. We do not accept the makers' analyses. We have independent analyses and a check analysis for each sample plate and for all deliveries; the resident inspectors watch every process of manufacture for every armour plate supplied. The right of selecting plates in process of manufacture and of firing at them is part of the contract. For ten years or thereabouts (since all-steel armour was adopted), this method has proved successful. We have never had a sample plate picked out and fired at that has not succeeded.

In England, we are supposed to be backward in the manufacture of nickel steel, so it may be worth while to state that the first nickel-steel armour was probably fitted on British ships. In making our early trials on nickel steel, two plates were submitted by different manufacturers. One contained about 5% of nickel and the other about 1½%; nickel was then costing over 60 cents per lb. Both plates stood the test, and we paid no more for that which contained the higher percentage of nickel. Since that date, much has been learned by armour manufacturers as to the use of nickel alloys.

While great value attaches to scientific investigations in regard to the nature and quality of the material, such as are described by M. Baclé, in practice it is obviously necessary to have simpler methods of testing, which are based upon or modified by scientific investigations. This fact in no way lessens the merit of the modes of investigation described by M. Baclé, although they are not applicable in every-day work. In England, different authorities have insisted on tests differing from each other, as well as from the tests which were previously adopted for mild steel in France. As a result, we have suffered from a multiplicity of tests. The Standards Committee is endeavoring to simplify and make uniform British tests for steel, and from the constitution of the Committee, it is practically certain that before long this advantageous result will be reached.

It may be added that high value attaches to bending tests of steel. The question as to whether the specimens shall be quenched or not is subordinate to that of insistence on bending tests before the receipt of steel by inspectors.

Mr. Webster remarks that the temperature, finishing and rolling have a great effect upon the material. The speaker's experience does not bear that out, as far as cold finishing is concerned. In the early tests of very thin steel plates, cold finishing proved unsatisfactory. He entirely agrees with Mr. Webster on the influence of the finishing temperature on the quality. **Sir W. H. White.**

With reference to Mr. Schüle's remarks, of course it will be understood that we in England are quite in sympathy with M. Baclé's test, that is, the reciprocating bending test. We are in the habit now, especially in the matter of bar steel, of applying the bar test, and there is a strong feeling in its favor. The speaker refers more particularly to the limit of the elasticity in an exact form.

Mr. Stevenson. A. A. STEVENSON, ESQ., Burnham, Pa.[*]—Referring to the test with the microscope, the glass mentioned by Mr. Webster[†] was tried recently at the Standard Steel Works on some specimens from which micro-photographs had been taken, but the result was not very satisfactory.

As far as the value of the proposed test is concerned, and the practicability of the same, in the speaker's opinion, there are three points to be considered:

First.—The glass, as exhibited, does not give sufficient magnifications. Perhaps a glass of ten to fifteen magnifications might prove satisfactory.

Second.—The preparation of a spot on the forging or casting is another thing to be considered. It is not believed, however, that this would prove a difficult thing to do.

Third.—The fact that many inspectors are not familiar with microscopical work may prove a stumbling block for some time in the way of a general introduction of a test such as proposed by Mr. Webster. In order not to misinterpret what he sees, a man should have considerable experience with the microscope.

Mr. Snow. J. P. SNOW, M. AM. SOC. C. E., Boston, Mass.—It is very satisfactory to the speaker to hear the bending test advocated. It is doubtful if our present system of testing gives prominence enough to this valuable feature. In the past when iron was universally used, the cold bending test, when made by skilful men, was about all that was needed to insure good material. In using steel, we need the tensile test to determine the grade, but the ductility and fineness can best be insured by bending tests.

The American Railway Engineering and Maintenance-of-Way Association, a society composed of railroad officials, consulting, municipal and manufacturing engineers, technical instructors and others interested in problems of railroad construction and maintenance, with headquarters at Chicago, has recently adopted a general specification for material and workmanship of railroad bridges. This specification, which has already been laid before Mr. Robertson, Secretary of the English Standards Committee, contains the

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[*] Supt., Standard Steel Works.

[†] *Transactions*, Am. Soc. C. E., Vol. LIV, Part E, p 412.

Mr. Snow usual cold bending requirements on narrow specimens with planed edges. It also calls for the bending of eye-bar material of the full width as rolled, 180°, without annealing, about a pin the diameter of which is equal to twice the thickness of the bar. This is similar to the test recommended by Sir William H. White, and is certainly very important.

The nicked bending test advocated by the speaker in discussing the manufacture of steel has, for its essential object, the examination of the grain of the steel in order to show whether it has been damaged by improper heat treatment, as explained by Mr. Webster, or injured by undue segregation, irregular carburization or other causes, which might render it brittle.

In many nicked bending tests, by impact and otherwise, advocated by European engineers, an attempt is made to prove too much. An effort is made to measure the force of the blow with the idea of determining the tensile strength, the elongation and other features of the material. If the purpose of this test is restricted solely to detecting brittleness, definite and reliable results will be attained, and a valuable addition made to our ordinary commercial testing.

The scheme described accomplishes the bending by means of a roller. This is deemed preferable to any kind of percussion, because the granular appearance of the fracture varies with the speed at which the bend is made. In fact, it is possible to cause good, ductile steel to break with granular fracture, if nicked and broken by a blow of sufficient velocity. The object of this test is to show the difference between good and poor material, hence the fracture should be made by some means that will not make good steel appear crystalline. For this reason, a slow positive pressure is preferred to a blow.

This test is suggested as supplementary to the ordinary tests on standard test pieces and is intended solely to guard against occasional brittleness.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 80.

TESTS OF MATERIALS OF CONSTRUCTION.

TESTS OF TIMBER.

By Gaetano Lanza,* M. Am. Soc. M. E.

In consequence of the great importance of steel in construction, it is natural that the investigation of the properties of other building materials should be looked upon by the casual observer as of comparatively less importance; but the engineer knows that the amount of timber used in construction is so very considerable, that it still forms, and will continue to form, a most important factor in engineering work. Moreover, as the present source of supply of certain kinds in common use becomes exhausted, the need arises, either to discover new localities where they can be obtained, or else to find other species which will serve the purposes required. In the latter case the engineer needs to know the strength, durability and other resisting properties of the new timber, as well as all the characteristics that affect its use. In order to obtain the information, he must study the results of tests made upon specimens of the sizes and proportions that are used in practice, and such as involve knots, cracks, crooked grain, and other defects to the extent to which they are likely to occur in wood that is put into service. In considering, therefore, what has been accomplished thus far, by way of testing timbers, which will furnish results applicable to engineering practice, it is necessary to draw a sharp distinction between,

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* Professor, Theoretical and Applied Mechanics, Massachusetts Institute of Technology.

(*a*) the work that has been performed upon small pieces, where care has necessarily been taken to avoid the irregularities introduced by knots, cracks, crooked grain and other defects; and

(*b*) tests made upon full-sized pieces, where effort has been made to secure, in the tests, as far as possible, practical conditions.

Unfortunately this caution has often been neglected by those who have undertaken to deduce, from tests, conclusions applicable in construction, and, in many cases, experimenters themselves have neglected it.

The attempt will be made, therefore, while summarizing briefly what has been done in the former field, to call special attention to the progress thus far attained in the latter, which is the one that vitally concerns the interests of the engineer. The importance and value of results derived from full-sized specimens were recognized even by certain early experimenters, as by Buffon and Duhamel about 1740, who made some tests of full-sized oak beams, and by Girard about 1798, all of whose specimens were of considerable size. At that time, however, the relative merits of the theories of resistance to a transverse load, advanced by Galileo, Leibnitz, Bernouilli, etc., were still under discussion, and a number of experimenters sought to settle these theoretical questions by their tests of timber, rather than to obtain constants for use in such formulas as are in use to-day, and to learn the effect upon them of the various things that affect the beam, as knots, cracks, crooked grain, etc., degree of dryness, soil, and climatic conditions, as well as dry rot and decay. They did not realize that timber, on account of its lack of uniformity, as compared with metal, is not well adapted to the deduction of fundamental laws. The consequence of the above stated tendency was that even Girard, while testing for deflection quite a number of oak and fir beams and columns of considerable size, broke only six oak columns, and that others, who found the variations in full-sized specimens of timber troublesome, preferred small pieces for these reasons, as well as because of the greater ease with which they could be tested.

Leaving out of consideration, however, those early experimenters who were seeking to deduce fundamental laws as a result of their experiments, by far the greater part of these tests have been performed upon small specimens; hence, it is worth while to consider what have been the objects sought in making them, and what can be, and has been accomplished by them. Tests on small specimens of steel and iron are made for the purpose of determining the quality of the metal, and the effect upon its quality of the chemical composition, and of the treatment to which it has been subjected during its manufacture. In timber, the analogous quantities are the species, the effect of the site and climatic conditions, including the nature of the soil, the exposure, the prevailing wind, the range of temperature, and the moisture conditions during growth, also the condition of the timber as to moisture, etc., during its use.

Essential differences between the two cases are, that in steel and iron the process of manufacture throughout can be controlled, and an approximately homogeneous product secured; whereas, in the case of timber, most of the conditions of growth are beyond control, and, in addition, the fact must be realized that a tree, or even a full-sized timber beam, column, or other specimen is, itself, a heterogeneous structure, involving sapwood, heartwood, and a gradation from one to the other; an average, however, of the different parts will not serve to determine its strength, since the most strained fibers may not be of average quality.

Moreover, the tree is subject to various deleterious influences as knots, cracks, crooked grain, wind-shakes, and other defects, which are determined by the same climatic conditions that affect the quality of the fiber itself. If, therefore, an investigation is to be made of the effect upon the strength and other resisting properties of timber, of the site and other climatic conditions of its growth, and if this investigation is to be at all complete, it must take into consideration their effect upon the prevalence of knots, cracks, crooked grain, etc., and of the effects of these upon the strength of the timber. Indeed, in most cases of timber used for structural purposes, in any given species, these are the factors of greatest importance in determining the strength and other resisting properties of the wood, and, consequently, its value from an engineering point of view. It follows, therefore, that any investigation which leaves these factors out of account, however thoroughly planned and however well conducted, must necessarily be of a very partial nature; and the assumption should not be made that the results obtained, hold, in the case of full-sized specimens, where conditions exist which were not taken account of in making the tests. Thus, if the ratio of the strength of a certain kind of timber with 10% moisture to that with 20% has been determined from tests of small pieces, the assumption that the same ratio exists in the case of full-sized pieces with their usual quota of knots, cracks, etc., is not warranted. In considering, therefore, any set of tests of small pieces, the partial nature of the investigation must be recognized at the outset and the conclusions must be carefully confined to such as are warranted by them. Nevertheless, many persons have contented themselves with experiments of this kind, their chief reasons being the facts that those upon full-sized pieces involve greater complexity, heavier loads, a far greater amount of timber to be tested, and hence a great deal more work and expense; notwithstanding the failure to obtain results applicable in practice. Other considerations, which will not be repeated here, may be found among those made by the writer and W. K. Hatt, Assoc. M. Am. Soc. C. E.*

At the end of this paper will be given a list of references to experimental work along these lines, for which the writer does not claim completeness. Comments will be made, however, only upon a portion of these investigations, especially upon such as involve tests of full-sized pieces, and upon some others where the experimenters had in view a connected scheme of some magnitude.

The work may be conveniently divided into two portions, the first including that performed between the years 1700 and 1875, and the second all that has been accomplished since 1874. The situation in the eighteenth and in the early part of the nineteenth century has already been mentioned, and allusion has been made to the work of Buffon, which included a number of tests of oak beams varying in section from 4.23 in. square to 8.57 in. square, with spans varying from 7 ft. 6 in. to 30 ft.; also to that of Girard who broke six oak columns varying in section from about 4 by 5 in. to about 5 by 6 in., and in length, from 6 ft. 5 in. to 8 ft. 6 in.

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* "Timber Tests: An Informal Discussion." *Transactions*, Am. Soc. C. E., Vol. LI, p. 67.

Nevertheless, the earliest experimenters who had in view a scheme of any considerable comprehensiveness were Chevandier and Wertheim, the results of whose work were published in 1848. The questions which they set for themselves as the most essential to solve were the following:

I.—What is the effect produced on wood by gradually increasing loads? What laws govern the resulting changes of form, and what methods are applicable to woods for the determination of their mechanical properties?

II.—Do these properties vary in one and the same tree according to the orientation?

III.—Do they vary with the quantity of moisture contained in the woods?

IV.—Do they vary in one and the same tree, at the same height, from the center to the circumference, and according to what law?

V.—Do they vary in one and the same tree with the height, and how?

VI.—What is the relation between the mechanical properties in the direction of the fibers, and in the two directions at right angles to them at different heights in the tree?

VII.—What is the influence of the age of the trees?

VIII.—What that of the thickness of the rings?

IX.—What that of the exposure?

X.—What that of the nature of the soil?

XI.—What are the relations of the different mechanical properties of the wood to each other?

XII.—What figures can be deduced, and what results can be used in practice?

With such a comprehensive plan it is plain that any one experimenter can expect to make only very limited progress. Moreover, the timber they tested was obtained from only one region. While the greater part of their investigations was carried on by means of small specimens, 22 of the experiments were upon pieces of what are called commercial sizes, *viz.,* 11 of oak and 11 of fir beams, the largest of the former being about 9 by 10 in. in section, and 18 ft. in span, and the largest of the latter, about 11 by 12¾ in. in section, and 42 ft. 8 in. in span, though the list involved some as small as 3 by 3 in. in section, and also some oak boards tested flatwise.

The plan of Chevandier and Wertheim will serve to illustrate the class of problems that naturally occur, as a rule, to the investigator of timber whether he starts from the point of view of the forester, the botanist, the dendrologist, or the engineer. Moreover, in starting out upon any such plan it is all important that the experimenter:

1.—Avoid making the assumption that his results apply to cases where there are conditions which did not exist in his specimens;

2.—That he endeavor to plan the order of his investigation so as to obtain results of practical value as early as possible.

No further mention will be made of work of this kind preceding 1875, except to say that the constants given for use in substantially all engineering manuals before that date had come to be based entirely upon results derived from small pieces, the few full-sized tests having become gradually ignored. The result of such a condition was that, not only were the values given for use erroneous, but there was also great diversity, not only in the breaking strengths, but also in the factors of safety recommended, some manuals advocating 8 or 10 while most of the building laws of the large cities required only 3. In the case of timber columns, moreover, the experimental data, upon which the formulas given were based, were entirely inadequate and misleading, and by choosing the rules and values given in different manuals one could easily obtain for safe strengths values differing enormously from each other.

Passing now to a consideration of the work that has been done in timber testing since 1874, it may be considered under the following divisions:

I.—Tests in which the experimenter has set before himself a general scheme of considerable extent, as, for instance, the effect of climatic and other conditions upon the strength of the wood.

II.—Work performed upon full-sized pieces with the direct object of obtaining values for use in engineering practice, whether or not it is a part of a general scheme of considerable extent.

III.—Tests not included in the above.

I.—In some of these cases, notably in the work of Professor Bauschinger, both large and small pieces have played a part, while, in some, only small ones have been used. Among the principal investigations of this kind may be mentioned:

a.—The work performed at Munich by Professor Bauschinger, and published in 1883 and 1887.

b.—The work at Zurich by Professor Tetmajer and published in 1884.

c.—The work at the Government experiment station at Berlin by Professor Rudeloff, and published in 1889 and 1895.

d.—The work by the Forestry Division of the United States Government previous to 1898.

a.—In the ninth part of the *Mittheilungen* aus dem Mechanisch Tech. Laboratorium der K. Technischen Hochschule in München are given the results of an experimental study which Professor Bauschinger made of the strength of certain pine and spruce woods, in connection with their other properties, as specific gravity, age, time of felling, etc., but special attention is given to the variations of strength with their percentages of moisture. In the sixteenth part he gives an account of a series of tests of the crushing and transverse strength of the more important coniferous woods from different districts of Bavaria. In the transverse tests, the percentage of moisture was determined by experiment, and is recorded in the tables. Then sections were cut from the same pieces from which the beams were taken, and tested for crushing, one of them being rather wet, one having about 15% of moisture, and the third being drier; the actual percentage being determined in each case.

Among his tests will be found a considerable number upon full-sized specimens, some of the transverse being 11 by 11 in., with a span of 8 ft.

b.—The following is an extract from Professor Tetmajer's explanation of the scope of his tests. He says: The specifications for the tests of the Swiss building woods were drawn up, having in view the importance of the entire subject, as a compromise between the interests of construction and of forestry. In accordance with the wording of these specifications, we were influenced by the tendency on the one hand, to furnish to the engineer, strength coefficients useful in dimensioning his timber constructions, and, on the other hand, to present, in the clearest and most comprehensive manner feasible, the strength relations of the different parts of the log, and, as far as possible, also, the way in which they depend upon climatic and site conditions. He experimented upon 31 trees, the species represented being Pine, Fir, Larch, and Oak, and the tests being made upon their tensile, compressive, transverse and shearing strengths, and also upon specific gravity, percentage of moisture, etc., and upon what he calls the "work capacity" under transverse load.

c.—In 1884 there was established by the Minister of Agriculture, Public Lands and Forests of Prussia a Commission, of which Professor Martens, the Director of the Versuchsanstalt of Berlin was the chairman, to draw up a plan for a comprehensive set of tests on the relation of the strength of the principal kinds of Prussian timber to the site conditions. The result of their deliberations at the time was an elaborate set of tests of timber from three fir trees grown in the suburbs of Berlin, in order to determine upon the general plan. The account of these tests is given by Professor Rudeloff in detail,* and the series involves tests of tension, compressive, transverse, and shearing strength, percentage of moisture, etc.

Among the tests are four transverse tests of beams having sections from 9 by 9 in. to 11 by 11 in. and about 6 ft. span.

In the *Mittheilungen* for 1895, Professor Rudeloff gives an account of an elaborate series of tests of some very small specimens of African timber.

d.—Inasmuch as a discussion, by the writer, of the timber tests formerly made by the Forestry Division of the United States Government may be found in the *Transactions* of the American Society of Civil Engineers for 1903, it will not be repeated here. A few remarks, however, will be made later regarding the plan under which the Forestry Division is now working, and the work in which it is engaged.

II.—Some of the principal work of this kind, not already included in I, is the following:

a.—Timber tests made at Watertown Arsenal, the greater part of which are upon full-sized columns of Yellow Pine, White Pine, Oak, and Douglas Fir.

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* *Mittheilungen* of the Versuchsanstalt at Berlin, 1889.

b.—Tests made by David Kirkaldy upon full-sized beams and columns of a number of kinds of timber; and published by his son, Wm. G. Kirkaldy, in 1891.

c.—Tests made in the Laboratory of Applied Mechanics of the Massachusetts Institute of Technology since 1880, including tests of full-sized timber beams, columns, timber trusses, framing joints, etc.

d.—Tests made by Professor H. T. Bovey in the Laboratory of McGill University, Montreal, mostly upon full-sized beams of Douglas Fir, Oregon Pine, and Canadian White Pine.

e.—Tests made by Onward Bates upon full-sized White Pine stringers.

f.—The work under the present plan of the Bureau of Forestry of the United States Government, as shown in the circular issued in 1903, setting forth the plan for future work.

Timber tests of the kind included in this second division are now so numerous that they have already exerted a great influence upon the dimensioning of timber structures in both Europe and America. The results are very generally quoted in engineering manuals, are used by engineers, and are made the basis of the requirements of city building laws; and while some of the handbooks still give values based upon the older tests, and on results obtained from small pieces, most manuals and most building laws now prescribe unit stresses based upon the results of tests of full-sized pieces.

In considering, therefore, the plan for any set of timber tests suitable for the present day, the following should be borne in mind:

1.—The first object should be to obtain values from each kind of wood suitable for use in practice, and this can be done only by tests of full-sized pieces containing the usual number of knots, cracks, crooked grain and other defects that occur in service.

2.—In making a study of the effect of moisture, of climatic conditions, etc., upon the strength and other resisting properties of timber, their effect upon full-sized pieces containing the usual defects that occur in practice should be studied, and emphasis placed upon those conditions that have the greatest effect, instead of making elaborate investigations of some features that possess but little influence, while omitting other features that exert a great deal.

3.—It is important to observe the fact that in the case of a large number of woods the results of tests on full-sized pieces are not available in sufficient quantity to furnish the information needed by engineers, and it is very important to supply this deficiency.

4.—Tests of the effect of the various preservative processes upon the strength and durability of full-sized specimens.

It is not necessary to outline here a scheme for tests of timber, as a plan is to be found in the circular issued by the Bureau of Forestry of the United States Government in 1903, which is in harmony with the principles stated above, and as the views of the writer upon the subject of such a scheme have already been published in a letter contained in that circular, and also in the *Transactions* of the American Society of Civil Engineers already referred to.

It should be added that the first circular reporting results of work under the new scheme has just been issued by the Bureau.

APPENDIX.

REFERENCES TO TIMBER TESTS BEFORE 1875.

Parent	*Mémoires* de l'Académie des Sciences, 1707–1708.
Musschenbroeck	Introductio ad philosophiam naturalem Lugduni Batavorum, 1762, Tome I.
Buffon and Duhamel	*Mémoires* de l'Académie des Sciences, 1738, 1740, 1741, 1742, 1768.
Duhamel	Sur l'exploitation des arbres; sur la conservation et la force des bois, 1780.
Buffon	Œuvres, Tome X.
Perronet	Œuvres, 1782, Tome I.
Belidor	Architecture hydraulique, 1782.
Girard	Traité de la résistance des solides, 1798.
Rondelet	Art de batir, 1814.
Barlow	Essay on the Strength of Timber, of which the first edition appeared in 1817.
	Strength of Materials, of which there have been many editions.
Ebbels and Tredgold	Tredgold's Principles of Carpentry, of which there have been many editions. Also many other publications of Tredgold.
Dupin	Journal de l'École Polytechnique, 1815, Tome X.
Beaufoy	Thomson's Annals of Philosophy, Vol. IX.
Lamandé	Gauthey's Construction des Ponts, Tome II. Also in other works, as Barlow, Tredgold, etc.
Couch	Published in Barlow's Essay on the Strength and Stress of Timber.
Peake and Barralier	Published in Barlow's Essay on the Strength and Stress of Timber.
Bevan	Philosophical Transactions, 1829.
Brown	Experiments of Colonel Totten, *Journal*, Franklin Institute, 1831, Vol. XI.
Savart	*Mémoires* de l'Académie des Sciences, 1830.
Barlow	*Journal*, Franklin Institute, 1832, Vol. XIV.
Wheatstone	Philosophical Transactions, 1833.
Minard and Desormes	Poncelet, Mécanique industrielle.
Ardant	Poncelet, Mécanique industrielle.
Hodgkinson	Philosophical Transactions, 1840.
Bouton and Earle	Mineralized and Natural Timber, *Journal*, Franklin Institute, 1842, Vol. XXXIV.
Hagen	Poggendorff's *Annalen*, Vol. LVIII.
Denison	Experiments on the Strength of Various American Woods Exposed to Transverse Strains, *Minutes of Proceedings*, Inst. C. E., Vol. I, p. 26, 1837, and *Transactions*, Inst. C. E. Vol. II, p. 15.
Pacinotti and Peri	Il Cimento, 1845.
Rennie	Architect's Pocket Book, 1848, Jno. Williams & Co.
Chevandier and Wertheim	Mémoires sur les propriétés mécaniques des bois, 1848.
Burt	Strength of Creosoted Timber, *Minutes of Proceedings*, Inst. C. E., 1852, Vol. XII.
Moorsom	Strength of Kyanized Timber, *Minutes of Proceedings*, Inst. C. E., 1852, Vol. XII.
Lapparent (De)	Bois comprimé, 1854 (Cherbourg).
Dunn	Experiments of Captain Fowke on Transverse Strength of Pine and Oak, *Minutes of Proceedings*, Inst. C. E., 1856, Vol. XVI.

Haswell	Strength of Materials, *Journal*, Franklin Institute, in many numbers beginning with 1869, Vol. LXX. Also Haswell's Handbook.
Nördlinger	The Technical Properties of Timber, 1860.
	Der Holzring als Grundlage des Baumkörpers, Stuttgart, 1872.
	Oak for Paddle Floats, *Journal* Franklin Institute, 1861, Vol. LXXII.
Hawkshaw	Resistance of Wood to Compression, *Minutes of Proceedings*, Inst. C. E., 1862, Vol. XXII.
Fowke	Results of a Series of Experiments on British Colonial, and other Woods, 1867.
Wiesner	Einleitung in die Technische Microscopie, Wien, 1867.
	Die Rohstoffe des Pflanzenreichs, Leipzig, 1873.
Karmarsch	Handbuch der Mechanischen Technologie, First edition, 1837; later edition enlarged by Fisher, 1888.
Papworth	Beams, *Journal*, Franklin Institute, 1866, Vol. LXXXI.
Rodman	Ordnance Manual.
Rankine	Applied Mechanics, Civil Engineering, Machinery and Mill Work, etc. In all cases there have been many editions.
Thurston	The Torsional Resistance of Materials, *Journal*, Franklin
	Experiments on Torsion, *Van Nostrand's Engineering Magazine*, 1873, Vol. IX;
	Experiments on the Strength, Elasticity, Ductility, etc., of Materials, *Van Nostrand's Engineering Magazine*, 1874, Vol. X.
	Resistance of Beams to Flexure, *Transactions*, Am. Soc. C. E., 1874, Vol. III.
	Materials of Engineering; there have been many editions.
Trautwine	Pocket Book; there have been many editions.
Lyster	Tests on Large Beams, *Engineering*, 1875, Vol. XIX.
Laslett	Timber and Timber Trees, first edition, 1875, second edition, 1894.
Jenny	Hungarian Timbers, Vienna, 1873.

References to Timber Tests since 1874.

Smith, C. G	Pine timber, *Engineering*, 1875.
Thurston	Resistance of Beams to Flexure, *Transactions*, Am. Soc. C. E., 1875, Vol. IV.
Florenville	Note sur les bois Américains, *Genie Marit.* 1877.
Hatfield	Theory of Transverse Strains, 1877.
Ihlseng	The Modulus of Elasticity of Some American Woods as Determined by Vibration, *Van Nostrand's Engineering Magazine*, 1878, Vol. XIX.
	Velocity of Sound in Wood, Nat. Acad., 1877; *American Journal Science and Arts*, 1879.
Gibson	Compression and Transverse Strength of Baltic Redwood and Pitch Pine, *Minutes of Proceedings*, Inst. C. E., 1878.
Mikolashek	*Mittheilungen* aus dem Forstlichen Versuchswesen Oesterreichs, 1879 (Bohemian wood).
Thurston	Strength of American Timber, *Journal*, Franklin Institute, 1879.
Gottgetreu	Physische und Chemische Beschaffenheit der Baumaterialien, Berlin, 1880.
Kidder	Yellow and White Pine, *Van Nostrand's Engineering Magazine*, 1880, Vol. XXII.

Thurston	Yellow Pine, *Journal*, Franklin Institute, 1880; *Minutes of Proceedings*, Inst. C. E., 1881.
Trautwine	Shearing Strength of Some American Woods, Tests of Wooden Pins of Small Diameter, *Journal*, Franklin Institute, 1880.
Wellington	Experiments on Impregnated Timber, *Railroad Gazette*, 1880.
Kidder	Strength and Stiffness of Small Spruce Beams, *Journal*, Franklin Institute, 1881.
Lanza	Strength of Wooden Columns (full sized), *Boston Journal of Commerce*, 1881.
Thanneur	Note sur le Bois Quebracho, *Annales des Ponts et Chaussées*, 1881.
Watertown Arsenal	Tests of Metals, etc., as follows: (*a*) Wood from the Pacific Slope, 1881. (*b*) Full-sized timber posts, 1882. (*c*) California Laurel (small specimens). (*d*) Tests of small pieces of many kinds of timber made for the Tenth Census under the supervision of C. S. Sargent, 1883. (*e*) Columns of Douglas Fir (full size). (*f*) Expansion and Contraction of Oak and Pine, 1895. (*g*) Douglas Fir and White Oak columns (full size), 1896. (*h*) Full-size Yellow Pine and Spruce Posts, 1897. (*k*) Fire-proofed wood, 1898. (*l*) Old White and Red Oak posts (full size), 1900. (*m*) Douglas Fir and White Oak posts (full size), 1902.
Australian wood	Experiments on the Hard Woods of Australia, *Minutes of Proceedings*, Inst. C. E., 1883; *Transactions and Proceedings*, Royal Soc., Vict., 1882.
Kidder	Fatigue of Small Spruce Beams, *Journal*, Franklin Institute, 1882.
Nakumara	Ueber den anatomischen Bau des Holzes der wichtigsten Japanischen Coniferen, 1882.
Nördlinger	Druckfestigkeit des Holzes, 1882.
Bauschinger	*Mittheilungen* aus dem Mechanisch Tech. Laboratorium der k. Technischen Hochschule in München, (*a*) Heft IX, 1883, Untersuchungen ueber die Elasticität und Festigkeit von Fichten und Kiefern—Bauhölzer (Mitt. X). (*b*) Heft XVI, 1887, Untersuchungen ueber die Elasticität und Festigkeit verschiedener Nadelhölzer (Mitt. XIX). Ueber die Veränderungen der Festigkeit der Nadelhölzer nach dem Fällen (Mitt. XX).
Day	Microscopic Examination of Timber with regard to its Strength, Am. Phil. Soc., 1883.
Estrada	Strength and other Properties of Cuban Woods, *Van Nostrand's Engineering Magazine*, 1883, Vol. XXIX.
Lanza	Transverse Strength of Large Spruce Beams, *Boston Journal of Commerce*, 1882; *Transactions*, Am. Soc. Mech. Engrs., 1883.
Rothrock	Some Miscroscopic Distinctions between good and bad Timber of the same Species, 1883.
Int. Assoc. Test. Mat	International Association for Testing Materials, formed in 1895, having been developed from a series of Conferences. The meetings, whether as Conferences, or as an Association, have been held at: (*a*) Munich, 1884; (*b*) Dresden,

	1886; (*c*) Berlin, 1890; (*d*) Vienna, 1893; (*e*) Zurich, 1895; (*f*) Stockholm, 1897; (*g*) Buda Pesth, 1901. Methods of testing timber were discussed at some of these Conferences.
Perram	Experiments on Strength of Timber used in the Eastern Division of the Central Provinces of India; Professional Papers on Indian Engineering, 1884.
Tetmajer	*Mittheilungen* der Anstalt zur Prüfung von Baumaterialien am eidg. Polytechnikum in Zürich: (*a*) Heft II, 1884, Methoden und Resultate der Prüfung der schweiz. Bauhölzer.
Lanza	Applied Mechanics. There have been many editions, the first being that of 1885.
Pike	Tests of White Pine, Van Nostrand, 1885.
Martens	*Mittheilungen* aus den k. Tech. Versuchsanstalten zu Berlin: (*a*) Jahrgang 4, 1886, Ueber die Bestimmungen der absoluten Feuchtigkeit des Holzes-Schild. (*b*) Jahrgang 4, 1886, Resultate und Untersuchungen mit imprägnirter und nicht imprägnirter Holzproben, Böhme. (*c*) Jahrgang 7, 1889, Bericht ueber die im Auftrage des Herrn Ministers für Landwirthschaft, Domänen und Forsten ausgeführten Untersuchungen, Rudeloff. (*d*) Jahrgang 13, 1895, Versuche mit afrikanischen Hölzern, Rudeloff.
Campbell	Want of a Uniform System in Experimenting on Timber, *Transactions and Proceedings*, Royal Society of Victoria, 1887.
Thurston and Flint	Report of Tests of Nicaragua Woods, *Journal*, Franklin Institute, 1887.
Sergent	Résistance des bois à la flexion et à la compression, 1887 (Macon).
	Traité pratique de la résistance des materiaux, Paris.
Warren	Strength and Elasticity of Iron Bark Timber, *Minutes of Proceedings*, Inst. C. E., 1887.
Nördlinger	Zug, Druck, und Biegungsfestigkeit der Hölzer, Wien, 1888.
Tetmajer	Zur Frage der Knickungsfestigkeit der Bauhölzer—schweizerisch, 1885.
Unwin	Testing Materials of Construction, 1888.
Bates	Tests to Determine the Strength of Pine Stringers and Floor Beams, *Transactions*, Am. Soc. C. E., 1890, Vol. XXIII.
Nördlinger	Die gewerblichen Eigenschaften der Hölzer, 1890.
U. S. Dept. Agr	United States Department of Agriculture, Division of Forestry—Work on Timber Physics preceding 1895. The following list of the publications of the Division of Forestry, as a result of the Timber Physics work, and referring to Tests, is given in Circular No. 18, issued in 1898.
Bulletin 6	Timber Physics, Part I, 1892.
Bulletin 8	Timber Physics, Part II, 1893.
Bulletin 10	Timber—Characteristics and Properties of wood in general, with a list of the commercial woods of the United States.
Bulletin 12	Economical Designing of Timber Trestle Bridges.
Circulars 8 and 9	Results of Tests on Bled and Unbled Longleaf Pine.

Circular 12	Southern Pines.
Circular 15	Summary of Mechanical Tests on Thirty-two Species of American Woods.
Circular 18	Influence of Size on Test Results, and Distribution of Moisture.
Bovey	Results of Tests of White Pine of large scantling, Canadian Soc. Civ. Engrs., 1893.
	Le Quebracho Colorado, bois pour traverses des chemins de fer, Congrès des chemins de fer, 1893; *Railway Review*, 1893.
Hatch	Investigations and Tests of American Timbers, Report from Committee on Agriculture U. S., 1894.
Technology Quarterly	Results of Tests of Timber made in the Laboratory of Applied Mechanics, Massachusetts Institute of Technology: (*a*) Full-sized beams, 152 spruce, 63 yellow pine, 45 white pine, 17 hemlock, 2 yellow birch, 1 ash, 36 white oak, and also time tests of 26 spruce, 1894. (*b*) Full-sized columns, 10 spruce and 5 yellow pine without bolster, 8 spruce and 3 oak with bolster, 1895. (*c*) Full-sized beams, 7 maple, 8 hemlock and 13 spruce, 1895. (*d*) Full-sized beams, 16 spruce, 5 Norway pine, 1896. (*e*) Compression of timber across the grain, 1896. (*f*) Tests of 6 timber trusses, 1896. (*g*) Tests of 9 framed headers, 1896. (*h*) Full-sized beams, 42 spruce, 2 yellow pine, 1897. (*k*) Full-sized beams, 6 spruce, 1898. (*l*) Full-sized beams, 37 yellow pine, 18 spruce and 9 white pine, 1900. (*m*) Full-sized beams, 11 yellow pine and 18 spruce, 1901.
Roth	Timber, an Elementary Discussion of the Characteristics of Wood, 1895.
Bovey	The Strength of Canadian Douglas Firs, Red Pine, White Pine and Spruce (mostly full size), *Transactions*, Can. Soc. C. E., 1895, Vol. IX.
Assoc. R. R. Supt	Proceedings of the Fifth Annual Convention of the Association of the Railway Superintendents of Bridges and Buildings. Report of the Committee on Strength of Bridge and Trestle Timbers, Walter G. Berg, Chairman. This report gives a very good summary of tests of American timber up to that date. In addition to many to be found in this list, there are in Appendices N, O, P, S, T and U, references to tests of western timbers, many of which were full size, as follows: (*a*) Report of Washington State Chapter, American Inst. Architects on the Strength of State of Washington timbers; Experimenters, Talbot, Hart and S. K. Smith. (*b*) Miscellaneous tests of the Northwest and Pacific Coast timbers; Experimenters, S. K. Smith and Thurston. (*c*) Tests of California Redwoods; Experimenter, Soule. (*d*) Full-sized old and new white pine stringers; Experimenter, Finley. (*e*) Full-sized Beams of Douglas Fir; Experimenter, Wing, 1895.

Hood..........................Oregon Pine and Douglas Fir, *Engineering News*, 1896.

Thierry and Petitcollot........Rapport, de la Commission chargé de faire des expériences sur la résistance des bois résineux, 1896.

Johnson.......................Materials of Construction, 1897.

Kummer.......................Preservation of Timber, *Transactions*, Am. Soc. C. E. 1900, Vol. XLIV.

Thil............................Étude sur les fractures des bois dans les essais de résistance, Congr. Int. des Methodes d'Essai, 1901.

Debray and Menager.........Résultats des essais de compression, de traction, et de cisaillement, faits sur diverses espèces de bois, aux laboratoires de l'École des Ponts et Chaussées, Cong. Int. des Methodes d'Essai, 1901.

Olmsted.......................Tests on the Physical Properties of Timber, Reprint from Year Book, U. S. Department of Agriculture, 1902.

U. S. Dept. Agr................Preliminary Circular issued by Bureau of Forestry, U. S. Department of Agriculture, giving outline for future work, 1903.

Hatt, von Schrenk, Lanza, Johnson and Russell......Discussion on Timber Tests, *Transactions*, Am. Soc. C. E., 1903, Vol. LI.

U. S. Dept. Agr................Progress Report on the Strength of Structural Timbers, Bureau of Forestry, U. S. Department of Agriculture, 1904.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

TESTS OF TIMBER.

By Prof. W. K. Hatt, James E. Howard, Sir William H. White, and Prof. Gaetano Lanza.

Prof. Hatt.

W. K. Hatt, Assoc. M. Am. Soc. C. E., Lafayette, Ind. (By letter.)—The writer has already outlined his views in some detail,* and it will not be necessary, therefore, to make any extended discussion of Professor Lanza's paper.

The writer desires to support Professor Lanza's recommendation that tests should be made, in all cases, on material in sizes and conditions occurring in practice. It is a common procedure to perform tests on various species of timber from Persimmon trees to Douglas Fir, in form of small sticks. In the opinion of the writer, the results of such tests usually tabulated in scientific treatises are of no practical consequence. The results expressing the strength of two species like Hickory and Red Fir should not be tabulated together on the same basis of size of test-piece and moisture content. If it is desired to ascertain the structural value of a wood like Western Hemlock which is to be used for structural purposes, the results of the tests should be compared with the strength of a species like Long-Leaf Pine, the structural value of which has been known for a long time. Such a comparison should be based on tests of large sticks, both in the green condition and after the defects due to seasoning have had an opportunity to act. If it is de-

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* "A Preliminary Program for the Timber Test," authorized reprint from the copyrighted *Proceedings* of the American Society for Testing Materials, Vol. III, 1903; and "Timber Tests," an Informal Discussion at the Annual Convention of the Am. Soc. C. E., June 10th, 1903, *Transactions*, Am. Soc. C. E., Vol. LI, p. 67.

Prof. Hatt. sired to ascertain the possibility of using a wood like the Sweet Gum for carriage construction, the results of the tests should be compared to the strength of Hickory, as determined by tests on small, clear pieces, thoroughly kiln-dried, such as are used for carriage stock. The tabulation of the strength of different species which at present is by many considered to be the most authoritative quotes the results of tests on 4 by 4 pieces with 12% moisture as follows: Modulus of rupture of Long-Leaf Pine, 12 600 lb. per sq. in., and that of Hickory, 16 000 lb. per sq. in. The modulus of rupture of Long-Leaf Pine timbers of merchantable quality, in stringer sizes, in well-seasoned condition, does not average more than 8 000 lb. per sq. in., whereas, the modulus of rupture of the better grades of carriage-stock Hickory, kiln-dried, is nearer 30 000 lb. per sq. in.

As a further argument for testing actual sizes of material, it is well known that very often the effect of seasoning is to develop weaknesses, which, in large timber, result in failure under longitudinal shear, and that the determination of the effect of moisture on the strength of the wood fiber, as based on tests of small, selected pieces, will not necessarily give results that may be applied with safety to large timbers.

The strength of large sticks is certainly affected by the presence of knots. The matter is complicated by the fact that sticks with knots are usually of more rapid growth than sticks of clear timber. So we have the double weakness, that due to the interruption of the grain of the wood, and that due to the weaker quality of the wood itself. The reduction from the strength of the clear stick to the strength of the stick with large knots, such as to throw it into a second grade, is nearly 25% in the case of Loblolly Pine. The expression of the judgment of lumber inspectors, who have had large experience in observing the behavior of timber of various qualities, is found in the ordinary rules of grading, which discriminate against timber with knots. The results of the tests, so far developed, show that this judgment follows very closely the indication of the results of tests.

It must be recognized that the ordinary tests applied to timber, such as cross-bending, end compression and side compression, do not indicate the relative value for construction. With the various timbers, there are so many other factors entering into the problem, such as durability and hardness to withstand wear and tear at joints of frames, that the scale value, as determined by use, is much more accentuated than the scale value as determined by mechanical tests. For instance, the relative moduli of rupture of Long-Leaf Pine and Loblolly Pine of good grade are as the numbers, 8 000 and 6 500. The increased height of a beam of Loblolly

Pine needed to make up for this difference in strength is not very **Prof. Hatt.** great, and it is evident that the figures quoted do not represent the relative structural value of the two woods.

It seems to the writer that to determine the value of a new species for different uses, many other tests should be made than those we are at present making. An attractive field of experimentation is the determination of the ability of different timbers to undergo a repetition of stress, such a repetition as comes upon the fibers of a stringer in a bridge trestle.

The question of the influence of preservatives, or preservative treatment is a very important matter at present.

The Bureau of Forestry, United States Department of Agriculture, has under operation at present a series of tests on the commercial timbers of the United States. The work undertaken is in accordance with the ideas expressed by Professor Lanza, and, while it is certain that problems of scientific interest connected with the growth conditions of trees will not be neglected in the future work, the energy of the Bureau is at present devoted to an investigation of such problems as seem of immediate interest. These are the determination of the strength of structural timbers in large sizes, especially those of the Pacific Coast, and the effect on the strength of seasoning; the reducing factors, and the reasons therefor, due to knots, rapid growth, etc., and the investigation of the effect of preservatives.

At the Louisiana Purchase Exposition there was an exhibit of the methods and results of these timber tests and the actual operations of the tests to determine the effect of preservatives on the strength of timber were carried on. There was an actual tie-treating plant, consisting of a cylinder into which led pipes for steam, for vacuum, for air pressure, for creosote, and for zinc chloride, so that the various preliminary processes and the final preserving process could be applied to the ties. There was also a laboratory at which the specimens taken from these ties were tested, both under static conditions and under impact conditions. A new form of impact machine was devised for these special tests.

James E. Howard, Esq., Watertown, Mass. (By letter.)—Colonel **Mr. Howard.** Laidley, early in 1881, procured some White and Yellow Pine timber having a maximum sectional area of 234.9 sq. in. in order to make tests of single sticks and built-up posts. These were the first tests of sticks of large dimensions which were made upon the Emery testing machine at the Watertown Arsenal. Other tests soon followed with the same and other kinds of wood in both large and small sizes. The results of these tests were made public and may be found in the annual reports of the testing laboratory, entitled, "Tests of Metals," etc., published by the Ordnance Department, Mr. Howard. U. S. Army. It is thought that the Arsenal tests show the range in strength which may be found both in commercial timber of the larger dimensions and in selected stock for smaller specimens.

The principal woods for engineering purposes are: several kinds of Oak, Long-Leaf and Short-Leaf Pine, Spruce, and Douglas Fir. Full-sized sticks in these woods mean those of large cross-section. For many of the tough and strong, hard woods, small sticks represent the sizes used. The Watertown tests of 1883, with sticks 1.575 by 1.575 in., on material collected by agents of the 10th U. S. Census, represent sticks of the latter class. As is well known, those of the latter class commonly develop greater strength than those of the former. Visible defects frequently account for a considerable part of this difference. Results on the strength and compressibility of sticks from the butts, middles and tops of the pieces have shown the relative influence of position in the tree.

Uninfluenced by other conditions, the heavier sticks of a given wood are the stronger, representing more material in a given volume. Wood, in this respect, resembles some other materials of construction which are similarly influenced. Careful selection of the sticks, of course, is desirable in the use of wood for important places. In judging of the quality of the timber, much reliance has to be placed upon its general appearance. Timber does not usually make its way directly from the forest to the structure, and much interesting and valuable information pertaining to the influence of climate, soil and exposure is unavailable, since the identity of individual sticks may be lost in the course of milling and shipment. Stability of form under working conditions of exposure has a bearing upon questions of strength.

Sir W. H. White. SIR WILLIAM H. WHITE, PRESIDENT, INST. C. E., London, England.—The bibliography appended to Professor Lanza's paper is very valuable, but there is no allusion to the extensive work done by Isambard Brunel in connection with timber railway bridges, nor any reference to some recent experiments recorded in the *Minutes of Proceedings* of the Institution of Civil Engineers.

Having been brought up as a wood ship builder, the speaker is interested in this paper and agrees with the statement that one cannot tell from the test on a small sample what weight a log will carry. Some years ago he made interesting experiments to determine the value of timber in association with steel when subject to tensile stress. We were then building steel ships, with wood sheathing on the bottom, and it was proved beyond question that within the limits of elasticity the timber gave sensible aid to the steel under tension. Pieces of wood were taken and their extensions measured under different loads. The corresponding data for steel were determined, making it possible to estimate, for a given extension (within the limits of elasticity), what part of the total load sustained by a combination—formed by a steel plate to which a wood plank was bolted—was borne by the steel and wood, respectively. It was thus demonstrated that the wood sheathing on decks or shell-plating of ships contributed to longitudinal strength. **Sir W. H. White.**

GAETANO LANZA, M. AM. SOC. M. E., Boston, Mass.* (By letter.)—The writer is much obliged to Sir William H. White for calling attention to certain references to timber testing which he, unintentionally, omitted from his list. **Prof. Lanza.**

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* Professor, Theoretical and Applied Mechanics, Massachusetts Institute of Technology.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

HIGHWAY CONSTRUCTION.

Congress Paper No. 81.

HIGHWAY CONSTRUCTION IN THE UNITED STATES.

By James Owen, M. Am. Soc. C. E., Newark, N. J., U. S. A.

Congress Paper No. 82.

HIGHWAY CONSTRUCTION IN FRANCE.

By G. Forestier, Inspecteur Général des Ponts et Chaussées en retraite Membre Honoraire de la Société des Ingénieurs Civils de France, Ancien Professeur du Cours de Routes à l'École Nationale des Ponts et Chaussées,
Paris, France.

Congress Paper No. 83.

METHODS AND GENERAL DESCRIPTION OF MASSACHUSETTS WORK.

By William E. McClintock, M. Am. Soc. C. E.,
Boston, Mass., U. S. A.

Discussion of the Subject by

R. J. Thomas, Aylesbury, England.
Halbert P. Gillette, New York City, U. S. A.
W. R. Hillyer, Port Richmond, N. Y., U. S. A.
Henry Manley, Boston, Mass., U. S. A.
Oberlin Smith, Bridgton, N. J., U. S. A.
B. C. Donham, Seoul, Korea.
James Collier, Denver, Colo., U. S. A.
B. Cole, Tecumseh, Ala., U. S. A.
H. K. Barrows, Bangor, Me., U. S. A.
E. Purnell Hooley, Nottingham, England.
James Owen, Newark, N. J., U. S. A.

Note.—Figures and Table, in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 81.

HIGHWAY CONSTRUCTION.

HIGHWAY CONSTRUCTION IN THE UNITED STATES.

By James Owen, M. Am. Soc. C. E.

In the economic development of the United States, and in the more complete adjustment of transportation to trade, the roadways or highways are now resuming their place as necessary adjuncts to the system, and their construction and maintenance are considered legitimate engineering functions, worthy of technical treatment and requiring proper scientific research.

The early highway construction of the last century, while really of great importance and at one time a topic of national consideration, was practically an adaptation to local conditions of the Macadam system evolved in Europe, and was successful where climate and Nature were in accord with the methods in use, and it can be said that all highway construction in the United States has been carried out on the same principle—a mere following of traditional precedent with special treatment for localities.

It may be proper, at this time of resumption of road construction, and from the general interest manifested in the subject, to take hold of the topic in its entirety, and only look to precedent where conditions are propitious, and to that end the following natural phenomena are of paramount importance:

1st.—Rainfall,

2d.—Temperature,

3d.—Topography,

4th.—Geological formation.

In the consideration of these headings their inter-association is so varied that perhaps it were better to follow out their relation in road construction as the variations may occur.

To do this intelligently, another factor enters immediately, and that is the relation of the natural functions to mechanical construction, and, of necessity, a general classification of accepted constructive practise comes in. With small variation, the basis of road construction is what may be termed the water bond. This term is used for lack of any accepted professional name, and explains itself from the fact that the medium of consolidation is moisture; either water deposited by Nature, mixed artificially, or by the use of moist natural material. The water bond, when in accord with suitable climatic conditions, is successful; but, without such conditions, trouble arises and substitutes are demanded. Thus far, however, no systematic practical study has been given to the selection of such substitutes.

Sporadic successes have occurred, which have induced further attempts, and the medium of consolidation of road material may be classed under the following heads:

1st.—Water;

2d.—Natural material with inherent mechanical bonds;

3d.—Natural oils and their components, such as tar and bitumen;

4th.—Natural rocks with cementic or binding capacity.

The relation of the classification to the natural conditions must then be considered, and this introduces another subject, also correlated, and that is the principles of road construction as generally accepted by the profession.

The constructive principles of good road construction demand that approved road material shall be used as a wearing surface for travel; the details vary, in that larger or smaller stone is used in the lower stratum, but it has always been considered that material for the wearing system should be the best obtainable. This principle, to-day, is open to variation, inasmuch as it has been found more economical, and quite as desirable, to use local material of inferior character on a secure foundation brought from a distance, as to bring all the material from remote sections.

Another subject of traditional interest here comes in, namely, drainage, but the rigid rules of absolute drainage heretofore required in all road practise lose their force in the consideration of road construction in a rainless district.

Having outlined the general scope of the subject, special consideration of the varying items will be in order, but it must be remembered that road construction in the whole country is the main subject of treatment in this paper.

Unquestionably, the governing natural influence on road construction is rainfall. On it depends the treatment of drainage, selection of material, detail of construction and future maintenance. The maps, published by the Weather Bureau, at Washington, show a variation of rainfall from 2 to 70 in. in the United States. It can be readily seen that a road constructed to be permanently good with 70 in. of rainfall cannot be of the same character as one constructed for 20 in., and thus the necessity for a departure from general practise can be appreciated.

Incident to this is the character of the rainfall, whether spasmodic or distributed. For instance, a rainfall of 23 in. in Texas, all falling within the space of two months, is of no practical benefit, but is a detriment to road construction and maintenance, and such a territory can be classified with the arid regions.

Topographical considerations are also complicated with the rainfall: As a rule, in the United States, except in the Louisiana district, the heaviest rainfalls occur in the mountainous regions, and such rainfalls are really destructive, especially as affecting maintenance, although the drainage problem is easily solved.

Interwoven with the rainfall is the question of temperature. In any given section where an isothermal line indicates that 1 ft. of frost enters the ground, it is a complete line of demarcation in road construction, and, to obtain correct results, the principles established for one region must vary from those of another.

It may be stated, therefore, that the present practise of road construction and maintenance is uniformly satisfactory for a rainfall of 30 in. and more. Traditional experience will ensure good results in many localities, while in many others, where there is a fall of even 50 in., there are such prolonged periods of drought that the water bond is inefficient. In the territory outside such limits, which include one-third of the area of the United States generally known as the arid and semi-arid regions, a radical departure from the traditional, accepted practise is imperative. In which specific direction this departure shall be guided is one of the live questions of present engineering practise.

In considering the treatment of the arid regions, as a rule, the temperature problem is eliminated, as the lack of moisture of course nullifies the effects of temperature, and, only in a small section of the Rockies and Sierras will the combination occur. There the natural abundance of proper road material will obviate much trouble.

The most serious combination of temperature and rainfall occurs in the so-called Middle States, a territory extending from Central Ohio to Central Kansas in longitude, and from the latitude of Central Kentucky to the Canadian boundary. This is the farming section of the country, requiring to-day immediate consideration of highway improvement. Here the climatic and natural conditions include a uniform rainfall of about 40 in., and a winter temperature sufficiently low for frost to penetrate below any proper construction. A very large portion is absolutely destitute of good material, and in many parts proper drainage is difficult to obtain.

In the northerly region, from Maine to the eastern slope of the Sierras, the question of latitude is paramount, as this is a region covered with snow for four months of the year, during which period there is no wear on the roads, but extra precautions have to be taken on account of the depth of frost.

The Louisiana region is also peculiar, with low altitude, excessive rainfall, incomplete drainage at all times, with incidental submergence and a great scarcity of good road material.

The foregoing allusions outline the possible extreme variations, and it can readily be appreciated that highway construction in the United States in the future cannot be continued absolutely on the basis of past experience, but that such past experience should form the nucleus or basis for intelligent development on systematic lines, based on the full appreciation of all inherent factors.

In the foregoing remarks, no allusion has been made to the character of the material for road construction, and seemingly, it may be an anachronism to relegate to secondary consideration what has usually been considered the prime factor, but, undoubtedly, careful appreciation of existing conditions will endorse such conclusions.

In deciding as to the availability of any given material for any given district, two factors should govern: First, the inherent qualifications of the material for proper road use, and second, its proximity to the region of use.

In the economic maintenance of any given road, eliminating the original construction of the road as being merely incidental, there must be made a careful balancing of the plus or minus character of the material as against the plus or minus cost of transportation, and this can only be determined by actual experience in any given locality.

To be more explicit: With a given road and given travel, an ordinary coating of trap rock will last only two years, but if such a covering of trap will last five years, it may be found more economical to renew the surface with cheaper material every three years. Here, however, has to be interjected the question of moisture, for an inferior wearing material will give better results in dry weather than a standard wearing stone.

To form a proper appreciation of the relative values of road material, the following materials are classified as suggested:

1.—Trap rock,
2.—Amicaceous granite,
3.—Ordinary granites,
4.—Hard limestones,
5.—Soft limestones,
6.—Hard silicious deposits, such as chert,
7.—Shales,
8.—Gravels and sands,
9.—Oyster shells.

The graduations of this list may be open to criticism, but they are based on the ordinary acceptance of standard road material. It may be, however, that a better appreciation of proper road construction, on the moisture and temperature basis, would modify the graduations.

Of course it must be understood that there is an enormous amount of good road material which seemingly may not be included in the foregoing category, but it will be simply a matter of experience to place such material in its proper order, and this experience can only be gained by use.

Incidental to the selection of the material thus classified, is the cost of transportation, and this cost may be divided into three items: wagon, railroad and water carriage. The first is a constant factor in all highway construction, and for general purposes may be assumed as uniform. The second and third are the most important factors in the determination of the selection of material, and in such determination another problem is introduced, whether it is always wise and economical to construct an ideal road, or whether departures, more or less radical, should be tolerated.

A problem of this kind may arise: a highway is to be constructed in a given locality with indifferent material available. First-class trap is only available by long railroad haul at a high cost. Which will give the more economical result: A judicious use of local material with periods, more or less lengthy, of poor road surface but easily remedied with careful maintenance, or, an up-to-date road of first-class material, laid down in first-class shape at a much higher cost? To be more explicit, the road is located in a gravel country; gravel gives an exceptional surface for ten months in the year, but is more or less rutted during the other two. Will it not be wiser to build the road of gravel at half the cost of the ideal trap road? It may be answered safely in the affirmative except where the volume of travel is so great as to warrant increase of expenditure.

Assuming this line of argument to be correct, the whole field of the various systems of road construction is open for professional consideration, but it will only be possible to formulate general ideas which may ensure judicious action in any possible case. It is proper to revert to the original schedule of natural phenomena for guidance at this point, and, if possible, lay down a few hard and fast rules.

Establishing a zone with a rainfall of 40 in. and a winter temperature inducing from 1 to 2 ft. of frozen ground, the ordinary accepted road practise may be endorsed with a few general remarks as to variations therein and a citation as to the merits of these variations.

Thus far, the new era of road construction has been confined mainly to this district, and the standard has been kept generally on a high plane by the adaptation of Macadam and Telford traditions. In the States of Massachusetts, New York, New Jersey, Pennsylvania, Ohio and Michigan, where for the last ten years road construction has been in progress, very satisfactory results have been achieved, valuable information has been acquired for future use, and the practise has been fairly uniform. Whether the best results have been obtained, only the repair account for a series of years can determine.

It may be proper on the part of the writer to allude to his own experience as some good results may ensue, so a few special points will be spoken of briefly.

In his selection of material but little chance of variation has been offered. Trap rock exists in abundance, and, for the wearing surface, is always used. It is the most economical material when the maintenance account is considered, obviously, therefore, nothing else should be substituted. In construction, Telford foundation is used almost uniformly, for after an experience of thirty years, it has been found cheaper to maintain. Strict insistence on hard stone for foundations need not be made, provided the materials are frost-proof, but a Telford foundation, properly laid and wedged, practically ensures at all times, a permanent basis for a uniformly good surface which cannot be obtained from a Macadam road. During the past winter with 4 ft. of frost in the ground, only six places, in 115 miles of road, were observed where the foundation was disturbed. In adjacent districts, under similar climatic conditions, where Macadam was used, the whole road for miles was disturbed in places.

Of course the question of grade modifies the rigid insistence of Telford, for on grades of more than 4%, Macadam is as serviceable as Telford. In regard to the economical results of maintenance, the experience of the writer is that Telford gives far better results than

Macadam. This is exemplified in two adjacent townships where Telford was laid in one and Macadam in the other. At the end of ten years the Telford roads were in their original good condition, but the Macadam roads, in the same space of time, necessitated an expenditure of 50% of their original cost to put them in good shape, the annual repair appropriation for the two communities, during the decade, being about the same.

The writer is somewhat urgent on this question of foundation, for, in his opinion, an enormous amount of money is injudiciously expended and unsatisfactory results achieved, from the fact that the maintenance account is unduly expanded. Insistence on Telford is only urged in the zone under consideration, where the natural soil is impervious and requires drainage, for when the frost is coming out of the ground, with 1 ft. of thawed ground on the surface and 1 ft. of frozen ground below it, there exists a condition of imperviousness, which, though lasting but a short time, is fatal to Macadam roads. Another point in favor of Telford pavement is that such construction is incidentally a drainage system, and as proper drainage is inherently demanded in all road construction, thus two results are achieved by the use of Telford in the zone under consideration.

In specifying the size of broken stone to be used, from 1.5 to 2 in. is the limit allowed. These sizes are found to give the best wearing results for an average travel, larger sizes making the road too rough and uneven and smaller sizes wearing out too quickly. A protest is offered here against the practise of using the output of a stone-breaker without screening. This is, in the writer's opinion, a fatal mistake which can easily be demonstrated. It will be readily seen that a trap-rock or granite block used in a pavement will wear very slowly, in fact even with the heavy wear on a city street a loss of only from 1 to 2 in. in ten years may be estimated. Take this same block and crush it in a stone-breaker and screen out the dust. Spread 1 in. of this dust on the surface of a stone road and, with the same travel as on a city street, it would last from 1 to 3 months and would then be thoroughly dissipated. Applying this principle to mixed stone on the highway, we have a variation in wearing capacity of say from 3 months to 3 years, according to the size of the stone. The result is, of course, an uneven and also an inferior surface in a short time.

Macadam laid down as one of his cardinal principles that the stone should be uniform in size, and this principle holds good to this day. With the introduction of proper screens no material need be wasted, but in hard road construction, the stone should be of uniform size in each layer, and care always should be taken in the process of rolling that each size be kept separate, and to this end, the introduction of what is known as "packing" has come into practise.

Probably no one subject has created more controversy, engendered more friction, and aroused more suspicion in the public mind, than the introduction of packing in road construction. Traditionally, there seemed to be no excuse for it, but Nature, with her variable climates, showed that, under certain conditions, traditional road construction would not last, and to get the proper results it was found that some extraneous material, other than stone, was required to ensure permanency, and this, for want of a better name, is generally known as packing.

The use of packing brings up two vital points in road engineering: First, the climatic adaptation of proper material, and secondly, the abandonment of the principle of clean stone. The use of other material renders the appellation "hard road" somewhat incorrect, and as such outside material practically has to be used in all road construction in the United States, the question of degree is the question of proper engineering.

Abandoning, therefore, the exclusive use of stone, and accepting as a correct principle the appreciation of packing, the field for investigation and research in road construction is narrowed to the plus or minus quantities which should be used to suit various climatic conditions. In fact, it is probable that the highways of the future will be in the nature of pavements in which selected materials with various qualifications will be used to the best advantage.

Generally speaking, the use of packing depends upon the character of the stone used, the time of year when applied, and the present and probable conditions of the weather. Basaltic traps cannot be consolidated properly without packing; softer traps require less, granite roads can be built without any foreign material, and limestone roads should have no packing at all.

As to the selection of material, various kinds of practise exist.

The writer prefers clay or loam and obtains good results. Other engineers use sand with equally favorable results, so a specific determination of proper material is impossible, except that it should be fine in texture, carefully and evenly distributed and then thoroughly rolled.

The practise of rolling is now considered an essential feature of road construction. The traditional practise of allowing the travel to wear the road smooth is a thing of the past, not tolerated in any community and generally prohibited by legislation. Whether the economic results from rolling are the same as from the wearing system may be open to question, but it is suggested that the principle of rolling roads should be adapted to resemble the wearing practise as much as possible, as undoubtedly a more homogenous surface will result. It is not the province of this paper to assert the advantages of horse or steam rollers. This is a financial problem entirely to be determined by financial capacity, extent of construction or maintenance, or material used. The ideal plant of to-day, however, is not complete without a steam roller.

Having alluded to some features of road construction now in vogue, it may be in order to speculate somewhat on the theory to be enunciated in the future as to the adaptation of existing practise to natural conditions, and it may be stated that there is a broad field for investigation in theorizing between the clean stone roads of New Jersey, and the sand, clay or oil roads of Southern California, both equally ideal in results, but virtually opposite in practise. It may be seen at a glance that there is ample scope for divergence, and the problem for the Engineering Profession is to get the best economic results with the material at hand adapted to climatic conditions.

Taking the country at large it may be divided into five general districts:

1.—Rainfall of 40 in.; 1 ft. of frost; available road material;

2.—Rainfall of 40 in.; 1 ft. of frost; poor road material;

3.—Rainfall of 40 in. and over; no frost; good road material;

4.—Rainfall of 40 in. and over; no frost; poor road material;

5.—Arid and semi-arid regions.

District No. 1 has already been considered under general road practise.

District No. 2, generally applicable to the Mississippi Valley, is a district where new principles of road construction may have to be evolved to ensure economic results. This district is the granary of the United States, and has financial ability, but this ability has economic limits, and therefore the element of cost is important. The cost of hard road construction in the United States, with improved machinery and management, varies from $3 000 to $10 000 per mile. The average cost may be put at $4 000 per mile. A section of 640 acres would require two miles of road, and assuming the price of the land in such section to be $64 000, two miles of road at the present average cost would be 12% of the value of the farm. If property owners in a city were assessed 12% for paving the streets in front of their homes they would consider it high, and it is high.

It seems, therefore, imperative that the first cost of these roads should be reduced, and the question is, How can this best be done? It must be also remembered that first-class road material in this locality is scarce, and at this point, maintenance must again be brought into prominence for keeping a good road surface, with sufficient support for the load in the road, and sufficient protection from the effects of Nature.

The usual practise has been either to furnish this support on the surface, or to supplement this with a good foundation. A theory now may be advanced whether it may not be wiser to use the supporting power of some inferior material without wearing capacity, and on top of this, place another inferior material with fairly good wearing, but no supporting capacity. An exemplification of this idea may be seen in certain roads on Long Island, which have been constructed with a Macadam base and a gravel wearing surface. The roads are located in a gravel country and all that is necessary for proper maintenance is to dig out the sides of the road, or haul the gravel for the wearing surface a short distance, never allowing the stone itself to assume the function of wear. The adoption of this principle in the Mississippi Valley might be worthy of consideration, and any solid stone or baked clay, carefully laid and consolidated, might be used as a base, and local gravel, shale or other material which will wear satisfactorily if held in place might be used on top.

The writer himself has experimented with ordinary gravel on a Telford foundation for a country road with satisfactory results, especially from an economic point of view, as the cost of gravel was one-sixth of that of broken stone, and even an annual renewal of the surface with gravel would save money in the end.

Of course there is a large amount of material, other than gravel, which could be used with greater advantage, but gravel is only cited as a suggestion. The main point, however, to which particular attention should be paid, is that in the district now under consideration, a foundation is absolutely necessary, as no ordinary Macadam or gravel surface would be efficacious in the spring of the year.

The use of burnt clay, or gumbo, is considered seriously as a substitute for natural rock, but it may be doubted whether its use can be made available except for foundations, as its crushing resistant to direct load is small, but with a coating of wearing material on top there is no doubt but that it can be used with advantage. The cost of burning the clay can be balanced against the cost of shipping natural rock, and whichever is the cheaper can be used. It would be wiser, however, to expend more money for a first-class surfacing material on such a roadway, so as to relieve the lower course from any possible duty save as a support.

In many of the Central States there is plenty of limestone which will make excellent foundations. This could be laid first and for a few years a coating of gravel could be used, then, if more money is available, good wearing stone could be substituted, and the practise could, of course, then be continued. This suggestion only applies to the softer grades of limestone such as are obtainable in Eastern Missouri. Wherever a harder limestone can be found it may be used by itself without detriment.

There is also found in these States a natural silicate known as chert, novaculite, and other terms. This could be used with good economic results in undulating country, but whether it would prove as satisfactory in the flat section of Illinois is very doubtful to the writer, but in the absence of first-class material, substitutes of more or less efficiency must be supplied which, with good judgment and observant experience, should give good results in the end.

The following combinations are suggested:

Hard limestone of Macadam or Telford of standard type;

Soft limestone foundation with coarse gravel covering;
Soft limestone with chert, silicate or novaculite covering;
Gumbo foundation with hard limestone covering;
Gumbo foundation with first-class broken stone covering.

These suggestions can, of course, be multiplied indefinitely, but they enunciate the principle which should cover the Mississippi region. In reports from States in the region under consideration, we find that in the State of Illinois the central portion is destitute of road material; but gravel and stone are available in the northern and southern portions. In Indiana like conditions exist. In Missouri there are both rock and gravel, but as yet, transportation renders the cost prohibitive in some sections of the State. In Iowa there are gravel and limestone, and in Michigan there is good gravel all over the State with limestone in the southern, and trap rock in the northern portions. None of these States, except Michigan, has any first-class material, and from an economic point of view, the cost of bringing such material into this territory would probably prove a prohibition, at least at this time.

Extending the consideration of road construction to the Southern States, the problem is somewhat simpler. With the first zone disappears the frost, that great bugbear of road maintenance, and as a rule, there is plenty of excellent natural material, generally good drainage, and a good average rainfall, except that periods of drought which render maintenance difficult are likely to occur.

The Southern States for the past few years have been the region of experiment in natural material and without doubt the climatic conditions, there existing, enable more satisfactory results to be achieved.

And seemingly one of the most successful instances to date is in the construction of sand clay roads in North and South Carolina. Experiments have been made for some years, by using the local sands and clays, to ascertain the necessary proportions and proper method of mixing, and that section of the United States now has roads with good surface and lasting from 3 to 5 years without repairs.

The results of the experiments show the following requirements: Clean sharp sand with no rounded corners mixed with a ferruginous clay, with water as the medium. The mixture should be of such consistency that every part of the sand should be in contact with the clay, and the whole well-rolled. Of course good drainage is paramount in these roads.

With the elimination of frost action, the imperative necessity for foundation disappears, and the only two points to be guarded against are, extreme drought at certain seasons of the year, and supersaturation at others. With the prevalent material used, proper maintenance becomes more a matter of solicitude than the original construction. It is extremely doubtful whether the shales of North Carolina or the soft limestones of Georgia, taking them as samples, will give permanently good results, used as they are to-day, unless a mixture of better and harder material is supplied.

The Tennessee and Kentucky silicate roads are more satisfactory, the material is harder, and it is probable that with more experience in its use, they will continue to give complete satisfaction.

The mountain regions of the South can be classified with the stone-road region, but Louisiana and the Lower Mississippi region form a problem by themselves. With a rainfall of from 60 to 70 in., a large section of the territory with inadequate drainage and no available material except gravel, and in certain sections, stone, the writer is doubtful whether any compromise can be suggested in the way of permanent improvement other than good stone roads. Fortunately, water transportation from a distance is easy and cheap and the problem must be solved in that way.

It will be noted that while in the territories, so far alluded to, consideration has been paid to stone roads or the nearest available substitute, it will also be noted that in the suggested departure from traditional stone-road construction, the pavement idea has been to some extent elaborated, but no attention, as yet, has been called to the possible construction, in these regions, of a pavement with a cementing material inserted. This scheme suggests itself in the construction of the Louisiana roads for the reason that the oil section of Southeastern Texas is so close to the former State that the use of oil at its present low price may be a factor in road improvement. In considering this oil theory, the treatment of the roads of the arid and semi-arid sections of the United States comes to the fore.

All construction, heretofore specifically alluded to, has been known as the water-bond type. It may be said that the water-bond type in dry regions does not give good results, and is not suitable for such localities. The writer has carefully examined first-class stone roads constructed in California, which were of the accepted type for the average Eastern State, but were not satisfactory in this locality. Prolonged drought caused them to unravel and a good natural gravel would have been much better.

This experience will probably apply to all that section of the United States west of the 100th meridian and south of Salt Lake. The rainfall is small and apt to be spasmodic, and its occurrence is not of much advantage in water-bond construction.

What then shall be the practise in this region? It must be remembered that with no moisture or rain there is no frost, which eliminates one chief source of trouble. Where there is but little rain there is a consolidated natural soil with, of course, but slight cohesion, so it would seem that to supply some natural cementing material is all that is necessary to solve the problem.

The natural asphalt of Central California is available and is undoubtedly an excellent material. Its use in the streets of San Francisco shows its advantage, and its cheapness would warrant a trial of its use in a modified form for highway cementation. Experiments alone would determine the necessary amount of its use and the cost.

The natural oils of Southern California are also available, and their use is extensive and gives excellent results. An examination of the roads of Santa Barbara, where a thin layer of clay and shale is placed on the natural sandy soil and rolled, then sprinkled once a year with natural oil, shows that an excellent smooth surface is the result with an infinitesimal amount of care for maintenance. In the rainless and frostless regions this cementation property of natural rocks may now be considered a necessity, and if limestone roads can be constructed with a cemented surface the question of drought would not interfere. Of course in sections where good natural gravel exists, it can be used with satisfaction, the only objection being that it will grind up under wheel travel and blow away.

Of course it must be recognized that demands for good roads in an arid country are limited in comparison with those of a thickly settled section. It might also be considered that more money can be expended per mile, especially in irrigated regions where the price of land is very high. This point can only be determined by investigation of local questions and conditions. Distances are very long in these sections, and it will require a much greater ratio per capita to supply demands than it would in Illinois or Indiana.

It will be noted from the foregoing *résumé* that the proposition to depart from the traditional idea of stone roads *per se,* and investigate the possibilities of other methods of construction is not unreasonable, and in the future, it remains for the Engineering Profession to guide investigations and experiments on proper lines so that good economic results may be obtained. Before leaving this branch of the subject, attention should be called to the work of the United States Government, which has been in three general directions: First, the stimulation of road construction among the general public; second, the dissemination of proper knowledge of suitable road material, its location, availability and use, and, third, the publication of the inherent adaptability of the material itself as ascertained by chemical and physical analyses. To the writer's mind this Department is the basis of future road development, which if properly guided, will ensure success. The Department is young, still feeling its way, and it might not be out of order to make one or two suggestions which occur to a mind imbued with practical ideas only.

The first report on the testing of road materials, issued by the Department of Agriculture in 1903, contains an enormous amount of valuable information relative to the strength and other qualities of various road materials distributed over the United States. This information, while correct on the basis of experiment, may be misleading. The three main physical properties of road material, as classified in the report, are hardness, toughness and cementing or binding power.

The relative chemical and physical capacities of these properties are carefully ascertained and tabulated, but, in the opinion of the writer, other elements enter into consideration which vitally effect results. It must be conceded that the impact test would be a safe guide in determining that 1 cu. in. of western limestone has less resisting power than 1 cu. in. of trap rock, and no hesitation would be shown in the selection. But when the following comparisons, taken from the report referred to, are tabulated, the problem becomes more difficult to solve, and rather startling to an old road builder.

		Coefficient of wear.	Percentage of wear.
Limestone	Geneva, N. Y	13.9	2.9
Trap	Lambertville, N. J	14.3	2.8
Trap	Hunterdon County, N. J	23.8	1.7
Gneiss	Little Falls, N. Y	20.7	1.9
Granite	Asheville, N. C	18.6	2.2
Slate	Genesee County, N. Y	5.8	6.9
Trap	Huntingdon County, Penna	34.5	1.2
Limestone	Fayette, Ky	6.4	6.2

This list shows that the hard limestone of New York would be as serviceable as the Lambertville trap of New Jersey, and that the North Carolina granite would be superior to both. The writer's experience has led him to a different conclusion which is explained by taking into consideration three factors: First, and most important, the character of the fracture of the stone; second, the natural friability, and, third, the action of frost, which depends on the capacity of water absorption.

Alluding to the character of fracture of the material, Macadam laid down the rule that all stones for roads should be as nearly cubical in shape as possible, and the experience of the writer has shown that this rule still holds good.

Take two samples of the same rock and let one be laminated and the other cubical, and it will be found that the wearing capacity of the cubical material is at least one-third more than that of the laminated material, the same difference existing, although not to the same degree, in the same rock broken by different crushers. A crusher with directing jaws delivers the material in a more cubical shape than a rotary crusher, and for road purposes is more economical, although the cost of breaking stone by the rotary crusher is cheaper. Accepting these statements as facts, a modification of the tables of the Government report must be made in correlating the values therein given with the fractinate tendency.

In referring to the friability of stone this quality must be distinguished somewhat from its resistance to abrasion or impact; it is an inherent trait difficult to define and determine, and is dependent on size, fracture, character of travel and meteorological conditions. This question is forced into road construction by the prevailing demand, in already developed road sections, for a perfect and ideal surface. In illustrating this idea the writer must cite his own experience.

A trap-rock surface of 1.5 in. cubical-shaped stones, with a fair grade, well-rolled and kept from breaking, gives an ideally smooth road, especially if a judicious amount of packing is inserted. The enlargement of the stone from 1.5 to 2 or 2.5 in. will render the same road, under exactly the same conditions, rough and less satisfactory on its surface, and more suitable for trucking than for driving. Substitute for the trap a fair average granite. The 1.5-in. stone of that material would wear out much faster, leave a dustier road and cost more for repairs, but enlarge the stone to 2 or 2.5 in. and then there would be less difference between the first and second roads, the granite giving practically the same surface, of course wearing away faster, especially in wet weather, but having an advantage over the other in that it is less likely to break up in a period of drought. The natural conclusion of this comparison is that the extra friability of the granite is somewhat to its advantage under certain conditions.

If two samples of trap be used, one the close-grained basaltic and the other the coarse-grained syenite, their behavior in a road is entirely different, the basaltic trap wearing continuously smooth and the syenite trap having a tendency to become rough and uneven; the friability of the latter is much greater than the former when both are broken into the 1.5-in. size, but the difference ceases in the larger sizes, so it is safe to say, that it is impossible to formulate any particular rule as to the behavior of any particular material in any given locality, for experience alone will give the results.

A few remarks will suffice in introducing the third point, relating to the Department Report under discussion, namely, that of frost and its close associate, water. The writer is of the opinion that in the future there will be a broad line of demarcation in road construction on the basis of the frost line, and incidental to this the behavior of the material itself when exposed to frost. The experiments, as to the cementing power of rocks, made by the Department of Agriculture are interesting, but it is reasonable to presume that all cementing bond is destroyed when the ground is frozen to the depth of 1 ft. and the road is heaved by frost, and this is further aggravated by subsequent settlement in the spring. If there is any natural power of re-cementation in any material, it is well to know it, but it is also well to know its limits. The opinion of the writer is that success in highway construction with natural rocks should be dependent on mechanical cohesion rather than on chemical action, and only in sporadic cases should such a factor have weight.

In addition to the action of the frost on the road as constructed, its action on the material itself should have careful consideration. Every rock, suitable for average road construction, cannot be affected by frost, but in the interests of economy and in efforts to utilize any available material, the frost question may be vital. The writer was tempted, on one occasion, to use sandstone for foundation, but when he found that some of it crumbled away in the heat of the sun, his enthusiasm for extreme economy ceased. The action of frost on recipient material is, of course, fatal to permanent road construction.

These suggestions relating to the report under discussion are given with all proper appreciation of the valuable work done, but it might be added that if the men, who concentrate their energies on this line of investigation, would let the profession at large know more of the results of their labors, better results might ensue.

Heretofore in this paper, construction items and details have had free scope. It seems proper that the question of maintenance should not be passed by lightly, for as a matter of fact, the repair of highways is of more importance than the construction. Errors in original construction can be rectified by conscientious maintenance, but negligence and carelessness in keeping up originally good roads nullify all former efforts. The American people have been slow to appreciate the necessity of road repairs, a prevailing sentiment existing that a road built was a fact and required no further consideration. But with a proper injection of the needed stimulus and information there is little or no difficulty nowadays to obtain a sufficient repair fund for good road maintenance.

Of course the principles that govern road repairs are practically the same as those for construction yet, as a rule, the construction of a road is by contract, and the maintenance is by the action of an executive force, under municipal or political control, so the divergence in procedure is at once apparent.

In the original textbook on road construction, constant repairing and patching were considered fundamental. Twenty years ago the writer laid down the principle that patching is a mistake, and that repairs of highways should be in large sections. The experience of twenty years has not led to a change of opinion, and corroboration of the correctness of such is furnished by the adoption of the same principles in the maintenance of the highways of France.

Involved more particularly with the question of repairs is the reception of the pavement idea suggested in the early part of the paper. If in the interests of economy the departure is made of substituting a cheap wearing surface of less durability, it can be readily appreciated that the maintenance programme must be of a more extensive character, and to some extent, more complicated and continuous work will be demanded. Comparing the situation in general terms we have:

Block pavement	No renewal in twenty years.
Asphalt pavement	Renewal every ten years.
Broken stone, urban	Renewal every two or three years.
Broken stone, suburban	Renewal every three or five years.
Gravel or other natural material	Renewal every one or two years.

With a system of 50 miles of stone road, 12 miles would have to be cared for per annum, whereas if the roads were gravel from 25 to 30 miles would be on the list for repairs. In the latter case, the cost of raw material would be light, but the labor item heavy. A point which enters here, and while not professional is patent, is that in a given district the money expended for labor is more appreciated than the money spent for stone which may be brought from a distance. On the other hand the absolute necessity for repairs on an inferior road may compel a stricter feeling of obligation on the part of the community for such repairs.

In the general classification for repairs it is somewhat necessary to revert to the bond question for in the future it may be of greater moment than at present. In almost all regions where stone roads have been built, the water bond is the basis of repairs. In highly developed communities the sprinkling of roads is used as a means of economical maintenance, and in repairs in general the sprinkling cart is usually the close attendant on the stone wagon and roller. In large sections in the Eastern States where road repairs are systematized, long periods of drought that continuously occur interrupt the water-bond system, and substitutes have to be provided. The tendency of all stone roads in dry weather is to unravel and for the surface to become loose. An efficacious remedy is to cover the road in the late spring with a coating of screenings. This is costly, and a cheaper substitute is supplied by sprinkling the surface of the road when about to break, or before broken, with a light coating of loam or clay. The application of this material, with the travel, brings the surface back to its normal condition, unless a high wind blows it off, when further material has to be put on. It will readily be seen that this is an abandonment of the water-bond principle, but such an abandonment is justified by its successful result, and further, when it is considered that a gravel road to a large extent is exempt from the absolute necessity of water application in its maintenance, the field of exemption from this treatment extends immediately.

The following is an outline of the system of repairs of highways in the writer's locality, and it should be stated that, as engineer, he supervised the original construction, and has intimate although not direct connection with the maintenance.

These roads are known as country roads, and are approximately one-half arterial and one-half connections to the main streets. They have a total length of 110 miles, and are in Essex County, New Jersey.

Main arteries, extending into the city, with urban travel, population 350 000	40 miles
Width of pavement, all Telford: Main roads	20 ft. wide, 12 in. deep
Other roads	16 ft. wide, 8 in. deep
Number of road districts with supervisor in charge	20
Average length of each district	5.5 miles
Cost of repairs per annum	$45 000
Repair of pavements	$30 000
Trimming gutters and dressing	$15 000
Cost of repair, per mile, for pavement	$273
Cost per square yard per annum	2¾ cents

As stated previously, the repairs are done in sections of one or two miles at a time on each road, and the new surface is as carefully constructed as if for a new road. Three steam rollers and two road machines are owned by the county, and horse rollers are hired when required.

When it is remembered that the above cost is for a fairly thickly settled community with one city of 250 000 inhabitants and twelve other municipalities, it can be readily estimated that the repairs for the rural section will not be more than 1.5 cents per sq. yd. per annum, or with an average width of road of 14 ft., $120 per mile for an average main country road. Where a road is constructed for purely local accommodation, this cost will be less. These figures are given so that some tangible idea as to the cost of maintenance may be had, much uncertainty on that subject now prevailing.

Another system in vogue, and which is quite successful, is to let the repairs by contract at a special price per foot. With a conscientious contractor, and they are prevalent in road building, excellent economic results can be attained. Whether such a practise is universally applicable for stone roads may be doubted. For gravel or any natural material a contract system may be more easily applied.

Incidental to all general repairs in large sections, is, of course, the attention to local repairs, but if the principle is recognized that a road built uniformly will wear uniformly, the small items of necessary attention will gradually disappear. These principles of repair apply only to roads from which the top has worn off and only requires to be renewed, for it is entirely different when it is necessary to repair a system which has no foundation or where the foundation has disappeared in the maelstrom of 4 ft. of frost.

This problem of repairs is endless in its ramifications and the scope of this paper limits casual allusion to salient points, but the writer wishes to emphasize the importance of the repair of all highways built in conformity with modern practise, and reversion to aboriginal methods must not be tolerated. An instance of perverted methods in road repairs was brought to the notice of the writer in the case of a fairly good stone road which had been worn down to a rough surface. A plow and scraper were brought into requisition, the surface was scraped, and 1 ft. of good earth was placed on the top of the worn surface to keep it from further harm.

It is curious to note that while the Engineering Profession is still groping with the detailed construction of highways, the mechanical adjuncts of road building have experienced wonderful growth and improvement. From the old-fashioned stone hammer to the present thoroughly equipped, stone-breaking plants is a wonderful advance, yet it sometimes happens, and it is applicable in this case, that the most highly improved machinery, while delivering material at much less cost, does not deliver it with the same particular adaptability to the necessities of the case, and while a cheaper road can be obtained, it is often at a sacrifice of a portion of its excellence.

The economy of quarrying, breaking and hauling the stone has undoubtedly proved a great stimulus to road construction, but when a plant is designed for breaking stone for the market, to be used either for concrete or roads, the difference of the two standards leads to complications and trouble. This trouble, however, is not inherent, but incidental, and in time will disappear, but when trap rock can be quarried, carried to the breaker, broken, screened and deposited in cars or boats for 60 cents per cu. yd., it must be appreciated that a wonderful advance has been made in road building. Road graders now in use will level quickly the subgrade for the stone, specially designed wagons will deliver the stone continuously at the desired thickness, patent sprinklers will run before a steam roller, behind is a finished road.

The only caution the writer would suggest in the adoption of these appliances is to see that they are properly adapted to the ends in view. An assertion of extreme saving in the use of a certain machine may be true, yet the result may be detrimental to good construction. This thought can also be applied to the various claims of an extensive collection of road materials, which the particular owners think to be the best in the world.

There is still another point in highway construction which is so vital that it is hardly proper to pass it by, and that is, the cost of railroad transportation of road material, this being so varied according to the rates of different railroads, that no general rule can be formulated for the use or rejection of any particular stone on any particular road until the railroad rates are ascertained.

Some railroad companies appreciate the importance of a system of complete road construction and concede low rates, others are indifferent, and still others demand the ordinary rates which, in many cases, shut out the business entirely. It would be safe to suggest, however, that if a standard rate of, say, 0.5 cent per ton per mile—coal is handled for less than that—could be established, the question of good or poor material in any given locality could be easily settled, and if the railroad companies would consider such a rate, half of the trouble in a large section of the country would immediately disappear. This suggestion is respectfully referred to railroad engineers.

It will probably be in order, for a more complete understanding of the road question in this country, to give a *résumé* of the present status of road construction, and to do this a report from each State is here tabulated. The four States of the Union pre-eminently identified with the road movement are New Jersey, New York, Massachusetts and Connecticut. Each of these States is building roads under State supervision, and while the procedure is somewhat different, the results are working out to the same end.

New Jersey has been building its State roads for 10 years and has completed to date about 952 miles at a total cost of $4 500 000, or $1 500 000 to the State whose share is one-third, the annual State appropriation being $250 000. About the same number of miles of local roads have been built in the same period.

New York State appropriates $600 000 per annum and pays 50% of the cost. About 500 miles of road have been constructed. A proposition which will be voted upon is now under consideration for bonding the State for $50 000 000.

Massachusetts appropriates about $500 000 per annum, the State paying 75 per cent. So far the State has appropriated about $5 000 000 and has built some 500 miles of road.

Connecticut appropriates $250 000 per annum and the State pays two-thirds, sometimes three-fourths of the cost. About 450 miles of road have been constructed at a cost of $2 200 000.

Other States show marked signs of activity in road building as the following list will show, and it must be noted that roads built by municipalities are not included.

Alabama has no regular State road construction, but roads are being built in various counties, each county having its own method of construction, maintenance and repair.

In Arkansas the counties are building many roads, and the road problem is receiving serious attention. The farmers in many parts of the State are forming clubs which assist the County Judge by donations of money, labor or material.

California has done considerable State work within the past few years. A road is in progress from the eastern boundary of Yosemite Park to connect the roads of Mono County, passing through the main ridge of the Sierra Nevada Mountains at an elevation of 9 900 ft., at a cost of about $45 000 for 9.25 miles. The State has acquired the Lake Tahoe Road, from Placerville, Eldorado County, to the State line, 58 miles long and in good condition. This road requires $4 000 per annum for maintenance. The Sonora and Mono Road from about Sonora, Tuolomne County, to Bridgeport, Mono County, has also been taken by the State but as yet no appropriation has been made for its repair. Another State road will be built from Trinity County to Humboldt Company, a distance of 50 miles.

In Delaware the sum of $30 000 has been appropriated yearly for two years and a Commission has been appointed by the State to take charge of the State highways; it is also provided that their cost shall be borne equally by the State and the counties interested.

The State of Illinois is not constructing any roads, but a Good Roads Commission is now engaged in making a survey of all the wagon roads in the State. In many localities in the northern part, gravel and rock roads are being built by local effort at a cost of from $600 to $2 000 per mile for gravel and from $1 500 to $6 000 per mile for broken stone. While there is great interest in the question still the movement is viewed with suspicion by the farmers and often with undisguised hostility.

Iowa has made no State appropriation for roads but a bill was recently passed creating a Highway Commission at the Iowa State College, carrying an appropriation of $7 000 for the biennial period for road instruction and investigation work. The general trend of opinion is toward road construction.

Kansas builds no State roads, but public interest is so great that a private association has been formed with the purpose of permanent road improvement.

Kentucky is not building any State roads and has not for a number of years but a number of counties are constructing Macadam roads. Public interest, however, is steadily increasing in the question.

Louisiana is not building State roads, but the counties are enabled to divert part of their taxes for improvement of roads, and also build roads by levying special taxes with the consent of the property owners, the dirt roads first being improved, then gravel and Macadam roads built. A State Good Roads Improvement Association has been organized, as well as local county associations, and it is earnestly hoped that the State will make an appropriation to help those who are endeavoring to help themselves.

Maine pays its towns for the permanent improvement of main roads $200 each per annum, and for this purpose appropriated $20 000 during 1903.

Maryland so far has been investigating the road subject and has appointed officers to report upon material, etc., and the advisability of the proper expenditure of $200 000 recently appropriated for road work.

Michigan has an ancient law prohibiting the State from aiding in the improvement of wagon roads, or being engaged in any other kind of improvement of this character, but an amendment will be submitted to the electors at the next session, and if there is an overwhelming vote, State aid will be granted in 1906. A county law has been adopted similar to that of Massachusetts, by which roads to be built and repaired are in the care of a Commissioner. In this State there are more miles of good roads than in either Massachusetts or New Jersey, but owing to its size it never receives credit for the same.

Minnesota has no direct oversight of road work as it is all done under the supervision of various boards and commissions in different municipalities.

Missouri constructs no State roads, but while each Legislature passes road bills, the total results of road work in the State are poor, owing to the lack of suitable material in a greater part of the State and high cost of transportation.

New Hampshire, in 1903, appropriated $10 000 and provided for the appointment of a State Engineer, who shall prepare a highway map of the State, and plan a system of continuous main highways. The Governor and Council are preparing a bill for the next General Court providing fully for the inauguration of a system of State work and State expenditure in the future construction of highways.

North Carolina builds no State roads, but many of the counties have started to construct their own roads, Mecklenburg County being the pioneer.

In North Dakota no action has been taken by the State.

Ohio has not built any roads, but so much interest has been displayed in the subject that bills are now pending in the Legislature for the permanent improvement of roads.

Pennsylvania has just commenced building roads under the State Road Act and $6 500 000 has been appropriated. $500 000 will be available the first two years, $1 250 000 the next two years, and $1 500 000 the next two years. Applications for about 136 miles of road have been received from various parts of the State.

Rhode Island, in 1903, appropriated $100 000 for the construction of highways under the direction of the State Board of Public Roads.

South Carolina builds no State roads, but roads are being built by the various counties.

South Dakota builds no State roads, all road matters being in the hands of local authorities under the supervision of the County Commissioners, Township Supervisors and City authorities.

Tennessee builds no State roads, but some counties build roads at their own expense, having authority to make appropriations. Other counties build turnpikes and charge toll, and still other counties have bought up turnpikes and support them free for the public.

Texas builds no State roads, all roads being built under the jurisdiction of the various County Commissioners' Courts of the State.

Utah leaves the construction of roads with Boards of County Commissioners in each county. Counties that are not actively engaged in road work are agitating the question with a view to future improvement in road lines.

Vermont has been improving her highways with State aid for eleven years. The annual appropriation is about $100 000, and is apportioned to towns on the basis of road mileage. The construction work in every town in the State is under the supervision of a State Highway Commission, and the general public seems satisfied with the work accomplished.

Virginia builds no State roads, but several counties have received authority from the Legislature to issue bonds for the building of permanent roads. While public interest is stimulated, but comparatively few counties are yet at work.

In West Virginia the State builds no roads, leaving the question an issue in each county.

One of the vital points in road construction is the question of supervision. It was conceded in the early days, prior to railroads, that national supervision was the desideratum, and the tendency to-day seems to be in this direction. Town or municipal charge has, in most cases, not given satisfaction, and the county has been injected with better results. The assumption by the State, as in Massachusetts, New Jersey, New York and some other States, has so far been exceptional, but there is a strong prevailing sentiment for national appropriation, and, as a consequence, national supervision, and consistent and persistent movements are being made to that end. The writer thinks that this would tend to good results, for, in his opinion, the secret of successful road construction is a careful appreciation of the proper use of available material, and a rigid enforcement, on the part of constructor and contractor, of the proper details of construction. This rigid enforcement can only be accomplished by strict integrity and a proper knowledge of the work to be done, and this knowledge can be acquired only by experience.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS.

1904.

Paper No. 82.

HIGHWAY CONSTRUCTION.

HIGHWAY CONSTRUCTION IN FRANCE.

By G. Forestier.*

Translated from the French by
Paul A. Seurot, M. Am. Soc. C. E.

Historical.

Before the Revolution the roads in France were divided into main roads and parish highways. The main, or grand roads, were built and maintained by the Province or State. In the "Généralités" they were built and maintained by the Province by means of a personal tax, called "Corvée," for the grading and construction of the roadway, with appropriations furnished by the royal treasury for all superstructures.

During the reign of Louis XV, more than 24 000 km. of main roads were built in this way. By Decree of 1776, abolishing the "Corvée," the main roads were subdivided into four classes. By Imperial Decree, dated December 16th, 1811, there was established between the main roads, called Imperial Roads, a distinction based upon their construction, their importance, and upon the nature of the resources which warranted the money expended for their construction or maintenance. This decree classified the main roads in three classes; the maintenance of the first two being carried exclusively by the State, and the maintenance of the third being borne partly by the State and partly by the Departments. This same decree put the fourth class, specified in the decree dated 1776, in a class by itself, which was then known as "Routes Departementales" (county roads). These latter roads were not so extensively used as the main roads and the expense of maintenance was borne exclusively by the Departments.

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* Inspecteur Général des Ponts et Chaussées en retraite, Membre Honoraire de la Société des Ingénieurs Civils de France, Ancien Professeur du Cours de Routes à l'École Nationale des Ponts et Chaussées.

With the Decree of December 16th, 1811, was given a list of all main roads, the maintenance of which was borne wholly or partly by the State. In 1824 a new list was published by the Director General of Roads and Bridges. It differs from the first in the exclusion of the main roads situated in the territory retaken by the foreigners after the wars, and in the addition of a few Department roads classified, after 1815, as Royal Roads.

In 1824 the total length of the Royal Roads, already maintained exclusively by the State, was 33 586 km., of which only 14 288 were in good condition. Since that time, the main roads, which have been successively called the Royal Roads, National Roads, Imperial Roads, and now National Roads, have gradually increased in length by the construction of a few hundred kilometers near the frontier, as shown in the following table :

1872	37 200 km.
1880	37 350 "
1889	37 779 "
1898	38 015 "
1900	38 066 "

The parish or village roads have made up the nucleus of the "Petite Voirie" (maintenance of small highways), which comprised the following:

Town roads, built and maintained by the township and by special agents appointed by the mayors.

Highways of great communication and highways of public interest, built and maintained by village resources (personal taxes and additional centimes), with an appropriation granted by the Department, and under the jurisdiction of agents appointed by the prefects.

Common highways, built and maintained by village resources without any help from the Department, by agents appointed by the prefects.

In 1836, by Act dated May 21st, the special service, called "Service of Department Highways," was instituted. It was intended by this act to insure the maintenance of the highways then existing, by compelling the town to raise funds for their maintenance, under the direction of the prefect and the inspection of a *personnel* appointed by him. But, for the roads of greater importance, called highways of great communication, the highways of public interest, special Department appropriations were granted.

By Act of June 11th, 1868, a fund was created for the maintenance of parish highways. This fund amounted to 115 millions, and was intended to help townships which contemplated building more roads than their resources allowed. The advances or loans taken from this fund at 4% interest and amortization came to more than 535 millions.

The State did not stop there. The law of 1880 created a new fund of 80 millions, which, after being used, was replaced by annuities fixed by the financial laws. These appropriations distributed since 1880 amounted to 200 millions, and have provided for the construction of 64 500 km. of roads and 145 000 works of all kinds (small bridges, culverts, etc., during seventeen years). It may be readily understood that such appropriations are especially useful for the construction of bridges spanning important streams not previously bridged and which, therefore, entailed relatively high expenditures.

There are now in France several classes of roads and highways giving about the following total lengths:

	1872.	1900.
"Grande Voirie":		
National roads	37 200 km.	38 066 km.
Department roads	46 000 "	17 000 "*
"Petite Voirie":		
Highways of great communication	79 708 "	159 257 "
Highways of public interest	61 845 "	73 736 "
Parish highways	186 421 "	274 977 "
Town highways (streets and roads)	unknown	unknown
Village roads	unknown	unknown

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* Since the Law of 1871 gave to the General Councils the right to change the class of the Departmental roads, maintained at the expense of the budget without the help of the personal taxes, these roads in most of the Departments have been transferred to the "Petite Voirie" as highways of great communication.

It is estimated that the capital used for the construction of the National Roads amounts to the enormous sum of 8 900 millions, distributed as follows:

National roads	1 500 millions.
Department roads (including those which were abolished since 1871)	1 200 millions.
Highways of great communication (exclusive of abolished department roads)	2 700 millions.
Highways of public interest	900 millions.
Parish highways	2 600 millions.
Total	8 900 millions.

Construction.

It will be easily understood that in a service, the organization of which may be traced back to Trézaguet, who in 1775 was engineer of the "Généralité of Limoges," it is almost impossible to find uniform rules everywhere in keeping with the needs of the present circulation on the National Roads. If most of these roads have retained their strategic characteristics, they have ceased to be the main means of communication and traffic since the construction of railroads.

It is easily understood, also, that roads established upon old highways, built when feudal strife and warfare made it imperative that villages and inhabited centers be located on steep and high grounds, have grades much too high for the present needs, but that they are not altered because the cost of changing would be too great now that they are less useful. On the other hand, the few kilometers of National Roads which have lately been built in mountainous regions, were built under special conditions. All we can do is to show what is done in practice rather than to give specified rules. The construction of the road or highway may be divided as follows:

Grading of the subgrade,

Construction of the incidental works,

Construction of the roadway.

Grading of the road is done in much the same way as the grading of a railroad, and especially so since the specifications of M. Freycinet have somewhat compelled the contractors to acquire special machinery and plant.

The construction of the incidental works (such as culverts, small bridges, etc.) is the same as in railroad engineering; small resources being alone responsible for more economical methods. This is especially so on small highways, where the engineers try to secure, at lowest cost, all improvements possible. For this purpose the reinforced concrete of M. Considère seems to permit great progress.

The line of a road is characterized by the maximum grade, by the minimum radii of curves, and by the width of the subgrade and of the roadway.

The width of the highway depends not so much upon the number of wagons passing over the road as upon the frequency with which vehicles going at different speeds or in opposite directions pass one another. On the National Roads, where the mean traffic is 240 teams, the width of the roadway is fixed at 5 m. The widenings, which insure the exceptional passing of more than two wagons and where materials of maintenance may be stored, measure 2.5 m. The subgrade has an average width of 10 m. between the inside edges of the side ditches in the cuts or between shoulders in fills.

The ditches average 1.5 m. and 0.5 m., as mean depth, with slopes at 45°. In deep cuts through rock and for economy's sake, the depth and width of the cross-section are reduced, because the solidity of the ground allows steeper side slopes. Theoretically, the dimensions of the ditches ought to be calculated for the volume of water that will flow, the ground grade and the resistance of the ground to scouring. In some countries where torrential rains occur in summer the ditches on steep grades are so arranged as to reduce the superficial slope. Stone revetments protect the bottom and sides near the intermediate dams.

The radii of the curves connecting the tangents depend either on the speed of rapidly moving vehicles or on the number of horses hitched in tandem for slow moving or in pairs for public conveyances. Theoretically, to insure the stability of rapidly moving wagons, the radii ought to be larger when a curve connects two tangents on similar grades, and smaller when curves connect tangents on opposite grades. For horses hitched in tandem, this disposition should be reversed. Practically, the minimum radii are the same under these two conditions, and measure about 40 or 50 m. On National Roads some grades are still over 6%. They are the remains of old customs of a time when the coefficient of traction was 40 or 50 kg. per ton during rainy seasons.

A grade of 40 or 50 mm. per m. caused the doubling of the effort of the horses. On the other hand, when the National Roads were the only means of long distance traffic, relay horses along the roads gave the necessary help over all grades greater than 50 or 60 mm. per m. Now, that traffic is purely local, the relay horses have disappeared, and the road must be such that any ordinary team may be able to overcome all resistance without having to diminish the load beyond a useful limit.

In regions comparatively level, grades have been reduced to 30 mm. per m. In hilly regions they are still as high as 80 mm.

It is easily seen that the minimum radii of curves and the maximum grades are very important in determining the first cost of the construction of the road in hilly regions. On the other hand, it would hardly be wise to build at great expense a road which would be little used.

If a road were constructed by a syndicate of manufacturers for their own use, it is certain that all conditions of its construction would be studied and so carried out as to reduce to a minimum the annual cost of maintenance, of transportation, of interest and of amortization of the first capital invested. Unfortunately, roads are usually asked for by people who do not intend to bear the expense of construction, and are built by associations preoccupied by the cost only and unable to see that poor economies in construction will entail great cost in transportation.

The work of the road engineer is then very hard, as he has to contend with so many different and contradictory interests. Some think only of their comfort and of the time spent in transit, others of the economy in transportation resulting from the heaviest load that may be drawn by the team. Moreover, the condition of these highways should be different for horses and for wagons. When, in order to lessen the effort of traction, it is desirable that the wheels revolve upon a surface as smooth as possible, the horses need a rough surface on which they may, without slipping, give the necessary pull.

Roadways.

There are two kinds of roadways: Paved roadways, built with stones cut in a regular shape and placed by hand; and roadways built with broken stones of irregular shape thrown with shovels.

Paved Roadways.—The paved roadway was, in the 18th century, a luxury, used only on all main roads in the vicinity of the Capital and of improved towns. The paving stones were then cubical and of rather larger dimensions, allowing their several faces after being recut to be used successively for wearing surfaces. These changes, made at frequent intervals, permitted the stones to be turned over before the surface exposed to traffic was so worn as to prevent their further use. At first these paving stones were laid upon a sand foundation thick enough to distribute the load of the traffic upon the area of the subgrade corresponding to the resistance.

The mode of construction has not changed, but the sizes of the paving stones have. Owing to poor maintenance, the renewals were postponed, so that the upper faces of the paving stones became almost hemispherical, and it was impossible to use the stones in any other position. Therefore, the benefit of great dimensions was lost. To diminish as much as possible the tendency of the stones to become rounded, paving blocks have now a rectangular shape.

In streets with sidewalks and curbstones, the pavements are well maintained. But in roads passing through country fields the earth embankments abutting laterally are hardly sufficient. In order to improve this the dimensions of the outer paving blocks are larger. Perhaps it would be better to extend the layer of sand acting as foundation under an abutment, in order to distribute the load of the outer paving stone upon the same subgrade area as that of the other stones,

Broken-Stone Roadways.—Since Trézaguet (1775), the roadways built of broken stones are made in two layers, the upper one bearing the wear of traffic and the lower one acting as a cushion or foundation. If we use for the upper one the more resisting materials, we must not use for the lower one materials as fine as sand.

However, about 1840, M. Berthaut-Ducreux successfully used the sand foundation of an old pavement. At the present time, in the Indre-et-Loire, they advantageously use river sand for the foundation of new roadways. This method can be recommended only in cases where the engineer is sure that an appropriation sufficient for maintenance will be forthcoming. Otherwise he would risk seeing traffic become impossible, when the upper surface, having become too thin to resist the wear of wagons, would break and crack.

As a rule, materials too small for the upper layer should be used for the foundation layer, and the others ought to be used successively, proportionately as their size increases. Before Trézaguet, two layers of flat stones were laid upon the plain surface of the subgrade. He substituted a new method consisting in laying large stones on edge upon the subgrade, which had been curved to conform with the crown of the roadway.

This arrangement, criticised by Macadam, ceased to be used during almost the entire 19th century. Lately, however, some engineers seem to come back to this method in certain bad grounds. Perhaps it would be better to increase the thickness of small materials forming the foundation layer. This tendency is, perhaps, justified by the uncertainty of getting the appropriations required for maintenance. The layer of stones laid on edge insures a continuation of the traffic during bad times. Formerly stones thrown upon the foundations were broken on the spot and it was left to the rolling machines to tamp them and compact them into one whole solid roadway.

It may be said that Macadam, in a spirit of reaction against the customs of his time, made the quality of the materials and their crushing by wagons the principal subject of his book of instructions for road engineers.

In France, Polonceau, as early as 1829, while supporting Macadam's ideas, in reference to the suppression of the foundation layer for broken-stone roadways, recommended the use of binder and rollers to make the roadway compact and resistant before being opened to traffic. These rollers were first pulled by horses, and since 1860 by mechanical power. They have completely changed the construction of broken-stone roadways by permitting the use of materials, larger, harder, and more resistant, and by giving better surfaces from the day the road is opened. The first cost is not, perhaps, much less, but the unnecessary crushing of materials has been done away with, and the excessive cost of rolling on new roadways has been reduced to zero. We will see further on that the use of steam rollers, becoming more extensive every day, has furthermore transformed the method of maintenance.

The crushing of materials used for roadways is still done by hand in France. The results of using mechanical crushers for railroad ballast, do not tend to encourage their adoption in the construction of new roads. However, combined with a methodical sorting and sieving, these crushers could be used with a certain economy in constructing new roadways. The more homogeneous stones of similar size and shape could be used for the upper layer, while the more irregular stones could be used for the foundation, provided the small pieces be laid upon the subgrade.

MAINTENANCE.

Expenditures for the maintenance of the roadway can be divided into three distinct kinds, as follows: Cleaning, repairing local defects, renovating and compensating for general wear.

Cleaning consists in removing dust, mud, snow, dead leaves, and cleaning slopes and ditches. On paved roadways, especially in cities, detritus is very easily removed with appropriate machinery. On the broken-stone roadways these large automatic sweepers need to be carefully handled by skilful men to avoid the unnecessary wear of the surface. Scraping the shoulders and cleaning the ditches are still done by hand in spite of the special plows designed for that purpose, the use of which is, however, handicapped by the great number of crossings (entrances to private residences) spanning the ditches.

Owing to the solidity of paved roadways they have been deemed indestructible and very little money is spent on them on account of the insufficiency of maintenance appropriations. This is the reason why most of them have become impassable and why they should be abolished.

Nevertheless, if a paved roadway were maintained as it should be, if small repairs were constantly made, this kind of road would be now, as it was before, a roadway *par excellence* for heavy traffic. This is proved by Table 1, which gives a *résumé* of experiments made by Charrie-Marsaine when he was chief engineer of the Department of the North.

TABLE 1.

Items.	Load hauled by one horse.		Distance travelled per hour.		Work done, in hour-kilometer-tons.	
	Winter.	Summer.	Winter.	Summer.	Winter.	Summer.
Paved roadway *P*............	1 306 kg	1 395 kg.	3 300 m.	3 500 m.	4 309	4 882
Broken stone roadway *E*....	851	1 395	3 080	3 480	2 621	3 972
Ratio $\frac{P}{E}$......................	1.53	1.22	1.07	1.006	1.644	1.229

Paved roadways would be good enough for rapidly moving carriages with rubber or pneumatic tires, as is proved by bicycles and automobiles passing through certain streets of Neuilly. However, the maintenance of paved roadways of the National Roads, which still aggregate in France an area of 2 362 173 sq. m., on which the mean traffic is equal to 499.8 horses, amounts to 3 398 147 francs, which corresponds to 1 442.19 francs per km. and 288.55 francs per km. per 100 horses. If we deduct from these figures all that pertains to the maintenance of broken-stone sections, slopes and ditches, we have 1 369.32 francs per km. or 273.97 francs per km. per 100 horses. This last item is itself divided as follows:

For materials................ 871.06 cu. m. per km.
or 174.28 " " " " per 100 horses.
For labor.................... 498.26 cu. m. per km.
or 99.69 " " " " per 100 horses.

Broken-Stone Roadways.

Prior to 1775, the broken-stone roadways of the main roads were maintained by "Corvée." Once a year a certain quantity of stones more or less dirty was brought from bordering fields and broken on the spot. On this layer which sometimes had a depth of 50 cm., heavy trucks and coaches were allowed to pass, making deep and dangerous ruts.

When the "Corvées" were abolished, Trézaguet, engineer of the Généralité of Limoges, acting under orders from Turgot, changed this defective method of procedure. He gave to a contractor the maintenance of the road, on condition that a workman be entrusted with the superintendence of a certain length, on which it was his duty to keep ruts from forming. Such is the origin of the "Cantonniers" (road-menders), who were for a certain time the contractors for their "Canton" (County).

To-day the "Cantonniers" are day laborers paid by the administration having charge of the maintenance of the roads or highways. During the time when funds were lacking to build or repair a new road, economy was the rule. They repaired as far as possible local defects, thus compensating for general wear. In 1839, following Macadam's ideas, two-thirds of the appropriations were devoted to labor. The mean cost per kilometer was 989 francs, or, per kilometer per 100 horses, 395 francs, of which 246 francs were for labor at the rate of 1.52 francs per day, and 131 francs for materials that cost an average of 4.61 francs per cu. m., making 350 days of work per km. for maintenance of the road, 50 days per cu. m. of materials put in place, 28 cu. m. per kilometer per 100 horses.

When steam rollers were perfected and gave to engineers the means of transforming newly spread materials into a compact roadway, maintenance underwent a change, repairs being made in large sections and at once, instead of in several small places, thus undoubtedly delaying traffic. Some engineers go even further and recommend whole periodical repairs between which the roadway is abandoned to itself. This apparently economical method is anything but conducive to real economy because it increases the cost of transportation during the few years in which the roads are in poor condition.

Under the new conditions, the cost of maintenance is about 890 francs per km., or 370 francs per km. per 100 horses. But labor has increased from 1.52 francs to 2.84 francs and the cost of a cubic meter of materials from 4.61 francs to 7.74 francs, so that the mean cost per kilometer per 100 horses corresponds to:

125 days per km. for maintenance,
75 days for disposing of materials,
25 days per km. per 100 horses.

It may be interesting to find whether the method of maintenance by making repairs on large areas by new fillings of broken stones, subsequently rolled down, does not increase the effort and resistance to traction beyond reason. The comparison of experiments made by Rumkorf in 1820, by Morin in 1842 and by the

Paris Omnibus Company at the close of the 19th century shows that there is no cause for apprehension.

In the suburbs of Paris between the Saint Cloud Bridge and Versailles, Rumkorf found that the effort of traction was:

From 35 to 40 kg. per ton when walking, and

From 40 to 42 kg. per ton when trotting.

Morin, in 1842, made several experiments recorded in Table 2:

TABLE 2.

Vehicles.	STONE ROADWAY.					
	Very dry and very smooth.	Slightly wet, dusty with a few projecting stones.	Solid, with large paving-blocks and soft mud.	Solid, with ruts and a great deal of mud	With detritus and thick mud.	In very bad condition, with deep ruts and thick mud.
	kg.	kg.	kg.	kg.	kg.	kg.
Trucks (walking)	18 to 17	28 to 25	37 to 33	40	55 to 50	71 to 62.5
Wagons (walking)	15 to 12	21 to 27	27	33 to 27	40 to 32	56.6 to 43
Coaches walking	21	30	39	47	55	77
trotting	25	40	50	58	66	90

In 1895 the Omnibus Company found:

12 to 17.2 kg. per ton on Macadam in good condition and dry,

18 to 19 kg. per ton on Macadam in good condition but sprinkled.

During the last few years, the circulation of rubber-tired vehicles and fast automobiles has brought about new conditions which must be studied by engineers in the future, as bearing upon the construction as well as upon the maintenance of roads. We will point out what could be done in this respect.

1.—Construction of the Subgrade.—The great speed of automobiles running about 40 km. per hour requires not only greater radii of curvature, but also that the chauffeur or steersman be enabled to see as far ahead as possible, necessitating the leveling of all side slopes or the cutting of all trees planted along the inner curve.

In spite of all police regulations, a chauffeur will always have a tendency to steer along the chord of the curve, notwithstanding the danger of collision that may follow such action, when the transverse crowning of the roadway is kept on.

It then becomes necessary to give to the roadway, as well as to the subgrade along the curves, a cross-section with a surface plane sloped toward the center and super-elevated on the periphery. This has been shown in several trials, and particularly in the Department of Seine-et-Marne.

As to the width between shoulders or slopes, it should be increased from 6 to 7 m. to give all fast carriages a chance to pass without trouble an obstinate teamster who insists on keeping in the middle of the road.

2.—Maintenance.—The maintenance by partial sections and small areas, which, with due care, does not stop the running of bicycles able to follow a sinuous and tortuous path, is a serious obstacle to the circulation of four-wheeled vehicles equipped with rubber tires and chiefly with pneumatic tires.

If it becomes absolutely necessary to make a partial repair, it will be well to use concrete, as was done so generally in Seine-et-Marne in 1855 and afterward in the other departments by Dajot's followers. This method consists in spreading, on the spot to be repaired, a fill of broken stone with a certain quantity of moist binder, all of which is rammed until it becomes consistent. The surface is then leveled up by ramming and tamping small debris obtained from the crushing of the stones and which are screened in two different sizes.

In important repairs made on large areas by fill of broken stone rolled down, it will be well to leave on the side of the road a passage unobstructed by loose stones. This small stretch may easily be reserved for traffic when the work is done by means of a steam roller, which can finish its work at one place before being transported to another. This, however, would be almost impossible with a horse-driven roller, because it must necessarily follow one side of the roadway, then turn and come back on the other side.

Another consequence of automobiling on broken-stone roadways is the dislodging of stones from their beds. Under the heavy load, the rubber tire, if not pneumatic, adheres to these small stones, pulls them out of their beds, and projects them into the air. The materials thus dislodged do not offer any resistance to shock and crushing, and the amount of dust is very annoying. After an automobile race, the best road will look very much like a garden path after it has been scraped and raked.

There is only one prevention; swabbing all broken-stone roadways with pitch. Endorsed by physicians and hygienists, and called for by property owners along roads frequented in summer by automobiles to abate the nuisance of blinding dust clouds which spoil cottages and gardens, this method of coating roadways with pitch must be looked upon by engineers as an economical way of maintaining highways used extensively by fast pneumatic-tired carriages.

Let us see what are the best conditions under which this can be done. The cohesion of the roadway depends upon the cohesion of the materials embedding and surrounding the stones and whether they are damp or dry.

If, when the percentage of humidity corresponds to the maximum cohesion, the roadway be coated with an impervious layer, preventing all infiltration of rain and any evaporation of water held in the binder, the cohesion will remain invariable. The stones, being well embedded in a firm binder, will resist the wear of the wheels without any serious displacement. There being practically no friction of the stones, their wear will be reduced to a minimum, and the roadway being undisturbed, the cost of maintenance will be greatly reduced.

If, on the contrary, the pitch coating is spread over the roadway when the cohesion of the binder is not satisfactory, the materials will be movable; they will be displaced by the wheels and will wear out. The water-proofing coat will break while the amount of detritus will increase, and the cohesion and solidity of the roadway will decrease as soon as the surface water finds its way through.

The pitch water-proofing will be useless if the subgrade is not previously drained. Put on under good conditions, in a workmanlike manner and at the proper time, it will be a source of economy, the saving on wear and tear compensating for the additional cost, which amounts to 12 or 15 centimes per sq. m. at the present time.

Sprinkling with Westrumite, which gave such good results during the trial races for the Gordon Bennett Cup, May 20th, 1904, may be done with advantage in some cases, but it forces the pitch into the roadway by means of a rather great quantity of water, and cannot be relied upon to regulate the cohesion of the binder, as is the case with hot pitch swabbing.

It may, in a measure, abate the dust, but it will not keep it from forming, because it does not prevent motion and displacement of the stones and, therefore, their becoming worn out and creating dust.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 83.

HIGHWAY CONSTRUCTION.

METHODS AND GENERAL DESCRIPTION OF MASSACHUSETTS WORK.

By William E. McClintock, M. Am. Soc. C. E.

Massachusetts was first pledged to the good roads movement in June, 1892, by the passage of an act creating a temporary Commission to investigate and report conditions and recommendations.

An act passed in 1893 provided for a permanent Commission, for the laying out and rough grading by the County Commission, at the cost of the county, and for the surfacing by the Highway Commission. This act carried no appropriation, and the only good that resulted from its passage was of an educational nature.

The 1894 Act, amending the law of the previous year by placing the entire charge of building State roads in the hands of the Highway Commission, and requiring the counties to pay one-fourth of the cost is, with the exception of a few perfecting and strengthening amendments, the law under which State roads have been built.

The main features of the law are as follows: A commission of three appointed by the Governor for three years. Previous to 1900, the Chairman was elected by the Commissioners; since then he has been named by the Governor.

Commissioners of counties, Mayors and Aldermen of cities and Selectmen of towns may petition the Highway Commission, asking that certain described roads shall be taken as State highways. The Highway Commission may not take the initiative, but may choose from the different petitions. Any road becomes a State highway, on the filing, by the Highway Commission, of a copy of the petition, a description of the lay-out and a copy of the lay-out plan with the Clerk of the county in which the road lies; and also by filing a copy of the plan with the Clerk of the town in which the road lies. When a road once becomes a State highway, the Highway Commission has complete and permanent jurisdiction so far as structures in or under it are concerned, and the State is legally liable for accidents resulting from want of repair. The building of sidewalks is done by the cities and towns, and they are legally liable for neglect to keep them in repair. The cities and towns are required to break out the roads in winter, and are legally liable for defects due to snow and ice; they also have the policing of State roads. No part of a road once taken can be abandoned without the concurrent vote of the municipal authorities. All State roads are built by contract, by the municipal authorities if they so elect, otherwise by advertisement and sealed proposals. All work, both for construction and repairs, is paid for by the State. The counties pay back to the Commonwealth one-quarter of the amount expended in the respective counties; and the towns pay back to the State Treasurer the entire cost of repairs, up to, but not exceeding, $50 per mile, per year. This means that the State pays three-fourths of the cost of building and repairing all State roads; and, in addition, all cost of repairs on any particular road, in excess of $50 per mile, per year.

Since 1901, the Highway Commission has, in addition to building State roads, rendered assistance to small towns. This is done in two ways, *viz.,* by specific repairs on some petitioned roads, and by the purchase of heavy road machinery for use on town roads.

For the specific repairs, the towns are divided into two classes: First, those with a valuation of $1 000 000 and less; second, those with a valuation of more than $1 000 000. In either case, 5% of an appropriation is reserved to be used in building such a road as the Highway Commission directs. The amount which may be used in any town is 40% of the average appropriation for road purposes for the preceding five years. The first class of towns, or towns with a valuation less than $1 000 000, are not required to pay any part of the cost of the work. The second class of towns, or towns with a valuation in excess of $1 000 000, are required to raise an amount equal to that allotted by the Highway Commission. In both instances the towns, through the Selectmen, become contractors to build a certain length of road in a certain way, and the State's money is paid to the towns on the approval of the work by the Highway Commission. From time to time the Highway Commission has purchased seventeen steam rollers and two portable stone-crushing plants. These are loaned to the towns and are used either on town roads or on the roads built under the Small Town Act. The towns using this machinery pay for transportation, for minor repairs, and for operating. Most of the towns using the State machines are financially unable to raise the money for purchasing such high cost plants, and much good road work has resulted from their use, which otherwise could not have been done.

When the Highway Commission votes to build a certain piece of road, it causes careful surveys to be made, which show the physical features, both in plan and elevation. The grade is established by a profile and by cross-sections every 50 ft.; and, in fixing a grade, not only is the maximum grade kept in mind, but drainage, floods, damage to abutters, bad foundations and a balancing of cuts and fills, in fact, everything that will give the best results by the expenditure of the smallest amount of money.

All work is planned on an engineering basis, which may be summarized as follows: The Secretary, a civil engineer, is the chief executive officer. Five Division Engineers are charged with the care of as many divisions, and each Division Engineer has as many Resident Engineers as are needed to inspect properly the work in his division. One Resident Engineer is charged with the inspection of as many roads as he can look after properly.

The surveys are made by parties of three, and these parties also stake out the work ready for construction, and take the final cross-sections on which final payments are made. All contracts are made on the unit basis, instead of the lump sum or square yard.

One Office Engineer, with an assistant and a corps of draftsmen and computers, works up the lay-out plans, the grade, plans all small bridges and culverts, and makes the estimates of cost.

After a grade is adjusted in the office the plans and sections are turned over to the Division Engineer, who then makes a study on the ground with reference to the character of the soil, the effect of the proposed grade on the abutting property, the area of watersheds that drain across the road, and his report includes recommendations on all these points, and also on the location of materials, with an estimate of the cost of moving to, and placing on the road.

By this method the Highway Commission has been able to treat each part of each road in a manner to give the best results, by adjusting the work to the soil.

The Acts of 1892-93 were rather for the enlightenment of the Legislature, and provided for giving advice to cities and towns. The Legislature, in 1894, made an appropriation for building State roads. From year to year since then appropriations have been made, as follows, for office and administration expenses for building and maintaining State roads, for aiding small towns in building roads, and for road machines for use of small towns:

1894	$300 000.00
1895	400 000.00
1896	600 000.00
1897	800 000.00
1898	400 000.00
1899	528 500.00
1900	528 500.00
1901	533 750.00
1902	533 750.00
1903	622 450.00
1904	533 950.00
	$5 780 900.00

The Commission is not only charged with the building and repairs of State roads, but it also has to advise with cities and towns. In carrying out this part of the work, advice has been given to municipalities, surveys have been made, grades established, specifications drawn up, and the work of building supervised by the engineers of the Commission.

The work in the small towns, under the Small Town Act, has a much wider range than that on regular State highways. The amount of money available for this work is comparatively small, varying from about $200 to possibly $6 000. In many cases it simply means that a culvert is rebuilt, the grade of a hill reduced, or the drainage effected by opening the side gutters. Usually the part of a road petitioned for that is in the poorest condition, is the part repaired. When the amount of money available is sufficient, the road is surfaced with gravel, after shaping it to give it a good crown, placing coarse stone for a foundation over soils that require such treatment, putting in culverts when needed and reducing grades. On this class of work, it is not at all times practical to place gravel, as the available funds and traffic will not warrant its being hauled a long distance. Then the best of the excavated material along the road is used. The **V** drain, hereinafter described, is used to a great extent. Much of this work is done in the hill towns where the grades are heavy and long, and cannot be reduced materially without building entirely new roads. These hills are cut and filled as much as possible, but the finished grade may be as great as 10%, and, in a few instances, is 12 per cent. With the short, sharp pitches removed, waterways cleared, and a fairly good surface, these roads afford reasonable accommodation for the traffic which passes over them.

In certain sections where the old road is very sandy, the traffic light, and gravel not to be had, broken local stone is used. On porous sandy soil with no hills, the greater part of the cost of a road is breaking and spreading a thin coating of broken stone, usually about 4 in. deep, after rolling. The sand makes a good foundation and permits the surface water to pass quickly downward without any drains, culverts, or other devices for drainage.

The kind of machinery and its distribution over a State, indicates in a measure, what is being done in the way of building roads.

In 1892, there were in Massachusetts twenty-five steam road rollers, seventy-eight horse rollers, and fifty plants for breaking stone. Most of this machinery was located in the cities, although a few of the large towns owned a crushing plant. There was one private plant with a capacity of 350 tons per day which furnished broken trap rock to towns along the line of the railroad on which it was located. This plant was modern, and provided for screening the stone into three sizes and conveying it, when screened, into bins, from which it could be loaded without extra handling.

Most of the crushing plants, however, were set up without regard to economical handling, and the stone was not screened into sizes. At the present time there are 175 steam rollers and as many crushing plants. Seventeen steam rollers and two portable crushing plants are owned by the State, some are owned by private parties, and the rest are owned by the different municipalities. There are five large private stone-breaking plants which supply broken trap rock along the lines of the different steam railroads to all parts of the State accessible to the railroads. All these plants are supplied with crushers, engines, elevators, screens and bins.

The smaller plants are portable or semi-portable and are set up to reduce the length of haul to the minimum. The annual output of these crushers, all used on Massachusetts roads, is estimated at 325 000 tons.

In 1892, the number of men familiar with the best methods of building broken stone roads was small. There was no uniform system. For the most part the stone was unscreened, no attention was paid to its quality, the crown was very flat, and gravel or even clay was used as a binder. As a result of building in all parts of the State, large numbers of men have had opportunity to watch the work as it progressed, to work and even to act as superintendents, and to gain an experience that otherwise could not have been obtained. This experience has been of great value to local road officers in building their own roads.

It is not the plan of the Commonwealth to build all the roads, but to take those that are the main arteries, connecting the larger municipalities with each other, and important towns with the railroad stations. It is not an easy matter to estimate exactly the length of such roads, but a reasonable approximation may be had by assuming a certain percentage of all roads to be main roads, and varying this as the work progresses.

There are in the State, 17 800 miles of all kinds of roads outside of the cities. The Highway Commission has estimated that 10% of these will fairly represent the main roads, and that 1 780 miles is a reasonable estimate of what the State may build. The completion of this scheme would give 1 mile of road to each 4 sq. miles of area, and leave cross-roads, which will be cared for by the local authorities, 2 miles long on an average.

While the Highway Commission may not take the initiative, and can only act on petition, this has not in any way interfered with the plan as outlined, as only main lines of roads have been petitioned for, and the Commission has the choice in petitions. The work as carried out has been for the double purpose of building State roads, and for educating local road officers in such matters. This has been accomplished by distributing the money in fairly small allotments and building in a larger number of towns each year. The road selected to be built has, in each instance, been a part of a projected through road, and each through road has been extended each year from as many points as possible, with the total appropriation and fairly economical construction as the controlling factors. With the varying conditions in different parts of the State, there is a wide range in the length of road built for a given amount of money. In certain sections the cost may be $2 500 per mile, in other sections $25 000 per mile. The intention in each instance is to allot a sufficient amount of money to permit of reasonably low figures. It is possible that this method increases the cost somewhat at times, but the good resulting to the towns from this opportunity to observe the methods of building a first-class road more than compensates for this increased cost.

The work under this part of the State Highway Act is all of a permanent character, although the roadway surface may vary in quality, width and thickness. The thickness of the foundation and the surfacing of the roadway are regulated by the character of the soil; the kind of foundation depends upon the soil and location of materials, and the kind of material in the surfacing is determined after a study of traffic and location of materials. Broken stone is used more than other materials, as it is, in by far the larger number of cases, the best and cheapest. When the local conditions warrant it, gravel is used.

In towns more or less removed from the larger centers, those charged with the care of the roads had no opportunity to learn from experience, previous to the building of State roads. They might see good roads in their visits to some large town, but gave no thought to the possibility of such roads being built in their own towns.

There was also a certain feeling of disbelief in the usefulness of stone roads, and in the building of any good road over some stretch of clay or swamp land, which would withstand the rigors of the New England climate. The good condition of the State roads in the spring, and in each succeeding spring, tended to remove this disbelief as to stability. The ease with which loads could be moved over the hard, smooth roads gave rise to a feeling that effort was lost and time wasted on their unimproved roads. Then came a general feeling that good roads were possible and a necessity, and poor roads an extravagance.

Two or three years after the State road work began, some of the towns began to profit by the object lesson, and raised money to build the same kind of road. Year after year different towns have taken up the work, some of them without, but most of them with the advice of the Commission. Up to the present time, there have been built and paid for by the towns, about 650 miles of first-class roads. This kind of work is increasing each year.

The only restriction placed upon the Highway Commission, as to the expenditure of any appropriation made by the Legislature, is that not more than ten miles of State roads shall be built in any one county in any one year.

In allotting the money to the counties, the Commission has taken into account the miles of road and the population in the county and in the State, giving a value of three to the roads and one to the population.

In making allotments to the towns, the main through roads and roads leading to important railroad stations have ever been borne in mind. The amount allotted to each town has been sufficiently large to enable the work to be done at reasonably low figures. From year to year work has been done in different towns for the double purpose of giving an object lesson and gaining the support of the Legislature.

City or village streets are not built by the Commission. This work is left to the municipalities, and the completion of the State roads is often contingent upon this work being done by the cities or towns.

Up to the present time there have been built 604 miles of State roads. There are continuous State roads, 20 miles in length; State and improved town roads, 50 miles in length; and of these last two, with some short pieces to be filled in, 75 miles in length. Reports from those parts of the State where the improved roads are show an increase in the number of people at seashore and mountain resorts; enhanced value of real property; larger loads or a less number of horses and a marked reduction in the time upon the road, both for business and pleasure.

The cost of building State roads varies with local conditions, and has a range of from $2 500 to $25 000 per mile. The average cost has been reduced from about $14 000 per mile, in 1894, to about $6 200 per mile in 1903. The average cost of the surfacing is about $5 000 per mile.

Six different sections are in general use, the particular section selected being regulated by the character of the soil and the traffic. The width, thickness, and number of tons of broken stone per mile are shown in Table 3:

TABLE 3.

	Width, in feet.	Depth, in Inches.		Tons per mile.
		Center.	Sides.	
A	15	6	2½	2 429
B	15	4	2½	2 006
C	15	6	4	2 904
D	15	4	4	2 370
E	18	2	2	1 320
F	18	6	4	3 379

The depth given is after rolling, in each case except in Section *E*, which is only used over a well-compacted gravel road.

The broken stone has cost from $1.05 to $3 per ton, in place, including teaming, spreading, watering, rolling, and supervising. During 1903, local stone was used on thirty-five roads, trap rock on thirty-two roads. The average cost per ton was $1.63 for local,

$1.89 for trap and $1.75 for all stone. All stone is paid for by weight and is weighed by a sworn weigher.

All work is paid for on the unit basis, per ton for broken stone; per cubic yard for excavation, masonry and coarse foundation stone; per square yard for telfording and shaping under the broken stone; and per linear foot for guard rail, side drains and storm sewers.

The highest, lowest, and average cost, in 1903, of some of the main items are shown in Table 4:

TABLE 4.

	COST.			Number of contract.
	High.	Low.	Average.	
Excavation, earth	$0.55	$0.25	$0.39 per cu. yd.	72
" rock	3.00	1.00	1.83 "	65
Dry rubble..................	8.00	2.75	5.22 "	67
Cement rubble...............	10.00	6.00	9.01 "	9
Concrete.....................	15.00	4.80	10.78 "	69
Gravel	1.20	0.45	0.68 "	54
Guard rail	0.14	0.30	$0.23\frac{4}{10}$ per foot.	65
Side drains....................	0.50	0.25	0.41 "	44
Catch basins..................	30.00	20.00	26.43 per ba	21

The length of a day is fixed by statute at nine hours. The prices per day are: for laborers, $1.50 to $2; for a single horse and cart with driver, $2.50 to $3; for a double team and cart and driver, $3.50 to $6. Practically all the work is done by local labor on town and city contracts. Most of the labor is done by Italians on private contracts.

All State roads are built and maintained by the Highway Commission. In certain instances contracting for repairs, at the rate of $50 per mile per year, the State furnishing material, is found to be good policy. But most of the repair work is done by day work, by men selected for the purpose. All repairs are under the direction of the Division Engineer. The Division Engineer inspects all State roads sufficiently often to detect any defects, and orders repairs when needed. The general repairs consist of cutting weeds and brush, trimming trees, filling washouts, removing small stones that work out in dry weather, spreading on sand to prevent raveling of the surface stone, and maintaining the surface of the roadway. The roadway is maintained by continuous repairs, to give a true and even surface at all times free from depressions that hold water. This is done by using stone screenings that pass a ½-in. mesh, or these and broken stone that pass a 1½-in. mesh and stop on a ½-in. mesh.

Generally speaking, stone of this kind placed at the right time will compact in a short time under the ordinary traffic of the road without rolling.

It occasionally happens that a weakness of the foundation permits the formation of ruts in the surface. These ruts are filled with the kind of stone already described, until it is proven that the original road is really weak, when it is ripped up and rebuilt, or the thickness of surfacing is increased to prevent further rutting.

When the crown of the road is worn more or less flat, the surface is broken up, harrowed, and a sufficient amount of broken stone is spread on to replace the original crown. The length of time that a road will wear before resurfacing is required varies with the quality of the original material and with the traffic over the road. Some roads require such treatment in two or three years, while others that have been in use since the organization of the Commission are in good condition and will, apparently, last some years longer.

The average cost of generally maintaining the State highways has been about $106 per mile, per year. During 1904, several short sections of work that had shown marked signs of weakness were thoroughly rebuilt, and in the rebuilding heavy foundations of telfording or field stone were put in. The average cost per mile including this rebuilding was $120, and probably represents a fair average cost for the future.

An attempt has been made to determine the annual waste of broken stone, both for general maintenance and for specific repairs. In making general repairs, stone is used to fill slight depressions so as to maintain a good surface at all times. The specific repairs consist of placing a sufficient quantity of broken stone to replace the original crown.

On 32 miles of stone roads in different parts of the State, selected to represent climatic and soil conditions, and covering a period of 8 years, the average annual loss of stone was 0.92 lb. per sq. yd., per year. The least loss was on the sandy soil in the moist air of Cape Cod where it amounted to 0.06 lb. per sq. yd., per year. The greatest loss was on the clayey soil in the dry air of the Berkshire Hills, where it amounted to 2.2 lb. per sq. yd., per year.

The quantity of broken stone required to replace the original crown is shown by a study of 3.44 miles of road so treated. These were roads with fairly heavy traffic, and were in use from 4 to 8 years before the resurfacing was done. The annual loss of stone amounted to 55.4 lb. per sq. yd., per year, or 243.8 short tons per mile, per year. The cost of this work averaged 32 cents per sq. yd., or 5.17 cents per sq. yd., per year.

Massachusetts has already built about 604 miles of State roads, and expended about $5 780 900 for building and repairs. The net cost to the State, after deducting the county repayments, is $4 200 000. These roads are built and repaired by the State. The money is obtained by issuing bonds, running thirty years. The bonds are cared for by a sinking fund, and there has been paid out on account of these bonds an average of $37 000 per year. The counties pay back to the State one-fourth of all amounts expended by the State, both for construction and repairs, the amount so returned being $1 400 000. Thus it will be seen that each taxpayer in the State pays, first, on account of the State and, second, on account of the county.

The average cost, on account of the apparently large outlay by the State, has been 1.17 cents, annually, on each $1 000 of valuation. This covers both construction and repairs.

The amount paid on account of the counties varies with the expenditure in and the valuation of the county; for example, Middlesex, one of the large and rich counties, paid, in 1903, $15 381 for construction and $3 152 for repairs. This amounts to a tax on each $1 000 of 2.9 cents for construction and 0.57 cent for repairs.

To pay all the charges on account of State roads, in 1903, the taxpayer of Middlesex County paid on each $1 000 of valuation 1.17 cents on account of the State's expenditure, 2.9 cents on account of the county's expenditure for construction, and 0.57 cent for repairs. This makes a total payment by the taxpayer of 4.64 cents on each $1 000.

The policy of tree planting was inaugurated during 1904. Four thousand trees were purchased and set out with great care. The cost per tree planted cannot be given at the present time. They are set about 50 ft. apart, on both sides of the road, wherever there are no trees.

Particular care is taken to cultivate the natural roadside features of all State roads by preserving and properly trimming the trees and shrubs.

The type of road built by the State of Massachusetts is adapted to local conditions, and all the different types may be found within one town or even within a single mile. Preliminary studies are made, by the engineering force, of soils, drainage problems, gravel, stone, grades and traffic, and the type of road to be built is based upon the results of these studies. The question of grade is an important one in a hilly country, as heavy grades are not only a severe tax on the user, but a burden to the taxpayer to keep in repair.

In an old, settled country, any material changes in the location of the established roads are practically out of the question on account of the effect upon abutting property. Hence the problem is to secure the best possible grades by cuts and fills on the old roads. Under these conditions, it occasionally becomes necessary to leave grades that are in excess of what they should be.

On important parts of the main State roads, no grade exceeding 5 in 100 is maintained. If local conditions prevent a reduction of the old road to this grade, that part of it which cannot be so reduced is not taken by the State until local consent permits either a reduction of grade, or a new road around the hill. On main roads of less importance, grades are left at 6 in 100, when a less grade is impracticable. No minimum grade is established. Aside from hills cut to maximum grades, the grades are gradually trued up, with vertical curves at summits and low places. No attempt is made to eliminate light undulating grades.

Preliminary to a study of grades, levels are taken at intervals of 50 ft., and cross-levels to the location line on each side. The profile is plotted on 40 ft. to the inch, horizontal, and 8 ft. to the inch, vertical scale. The sections are plotted on a natural scale of 4 ft. to the inch.

A trial grade is first fixed on the profile. This is plotted on the sections adjusted to do the least damage to adjoining property and then changed until the excavation and fill balance. The usual allowance for shrinkage of different kinds of earth is made. When the fill is to be made over marsh or swamp, soundings are made to hard bottom, and an estimate made of the shrinkage due to settlement under pressure.

At points subject to overflow during floods, the highest high-water mark is determined as nearly as possible by study and inquiry, and the grade of the proposed road is fixed to prevent any overflow.

Where the land is level and subject to flooding during heavy rainfalls, on account of slow running off, the grade is fixed to have the subgrade, on which the surfacing is placed, above high water.

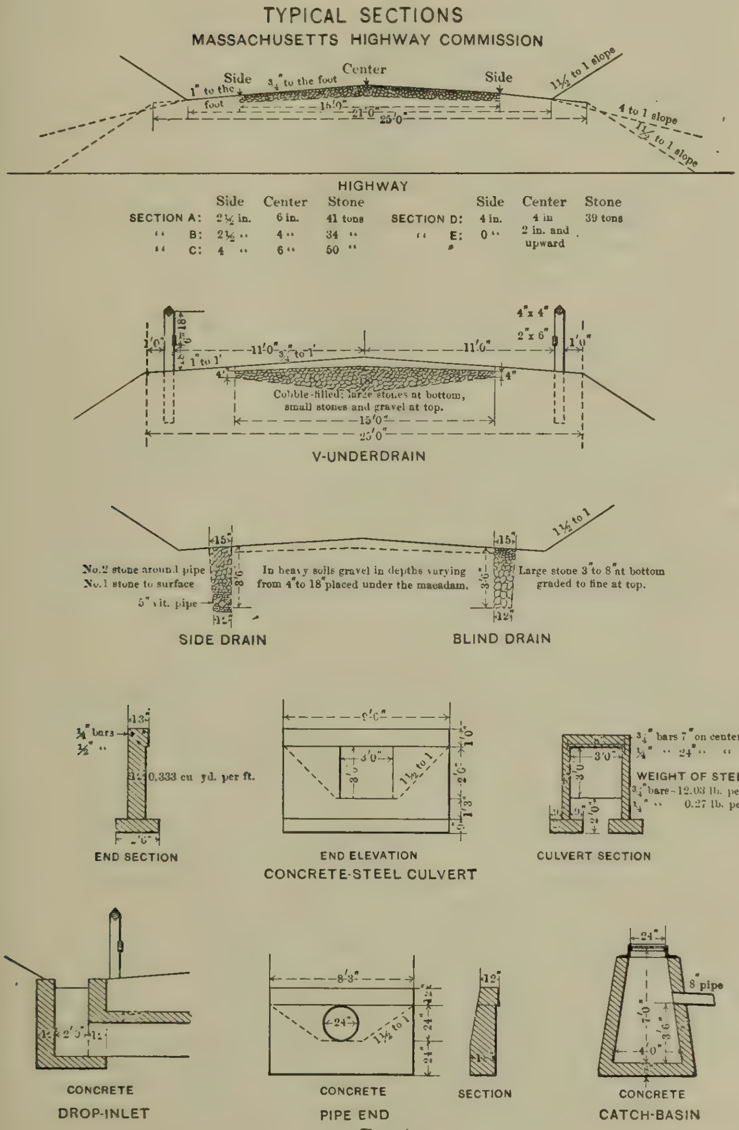
In ordinary soils all banks in cuts or fills are given a slope of one and one-half base to one rise.

Porous soils, such as sand or gravel, are not underdrained. Non-porous soils are considered unsafe in the subgrade unless the ground water is removed by some kind of a drain. Soils containing 25% of material that passes through a one-hundred-to-the-inch mesh, are treated as non-porous.

Three kinds of drains are built for removing ground water, *viz.,* "blind drains," "blind drains" with a clay pipe in the bottom of the trench, and **V** drains. Either the "blind drain," or the "blind drain" with a pipe in the bottom of the trench is placed on one or both sides of the roadway; on one side when the road traverses a side hill, on both sides at other times.

"Blind drains" with a pipe in the bottom of the trench are made by excavating a trench 3½ ft. deep, 12 to 15 in. wide at the bottom, and 15 to 18 in. wide at the top. A 2-in. layer of fine gravel or stone is placed in the bottom of this trench, and on this gravel a salt-glazed bell and spigot clay pipe is laid, with open joints. Fine gravel or stone is packed around the pipe, and to a depth of 6 in. over it. The rest of the trench, to the bottom of the surfacing material, is filled in with stones not larger than 6 in. in their largest dimensions.

A "blind drain" is made by excavating a trench about 3½ ft. deep below the proposed finished grade, 12 to 15 in. wide at the bottom, and 15 to 18 in. wide at the top. This trench is filled to the bottom of the surfacing with stones not exceeding 6 in. in their largest dimensions. The larger stones are placed at the bottom. Both these drains always end in a culvert or at some good drainage



	Side	Center	Stone
SECTION A:	2½ in.	6 in.	41 tons
" B:	2½ "	4 "	34 "
" C:	4 "	6 "	50 "
SECTION D:	4 in.	4 in	39 tons
" E:	0 "	2 in. and upward	

FIG. 1.

point. They are laid with a minimum grade of about $\frac{2}{10}$ ft. in 100 ft.

V or center drains are made by excavating a **V**-shaped trench in the center of the proposed roadway, from 10 to 15 ft. wide, from 18 to 30 in. deep in the center and from 12 to 18 in. deep at the sides. This trench is more or less carefully filled, to within 6 in. of the proposed finished grade, with stones from 4 to 10 in. in their largest dimensions, the smaller stones being at the top. A steam roller is passed over the surface of these stones until they are thoroughly compacted and all settlement ceases. Trenches are cut in the sides from the center of the **V** trench with a slope to the bottom, ending in the gutters, at intervals of about 50 ft., and are filled with coarse stone. No side drains are used when this **V** drain is put in.

Culverts are built wherever it is necessary to carry surface water under and across the road. They are placed at all brooks and ditches, at low points where an embankment crosses the same contour twice, and on hillside roads at intervals, to prevent an undue accumulation of water in the gutters. Culverts are built of iron pipe, clay pipe, rubble masonry or reinforced concrete. The ends of all culverts are protected by masonry or concrete. Iron pipes are used when they have a small cross-section and are of necessity placed near the surface. Clay pipes are used when the required cross-section is small, and they can be laid 4 ft. or more below the grade of the road. All joints in clay pipe are carefully cemented. When the culvert opening required is larger than an 18-in. pipe, box culverts are built. If of masonry, they are built of dry rubble, the stones having good bed and build, and the walls being thoroughly bonded. The covers are of flat stone from 12 to 16 in. thick, and all joints are thoroughly filled in with stone laid in cement mortar. If of concrete, the concrete is of Portland cement, sand and broken stone in the proportions of one part cement, two parts sand, four to five parts stone. Twisted steel bars or square twisted rods are embedded in the concrete to take all tensile stresses. The side walls are fairly thin, reinforced by buttresses when more than 3 ft. high. Both abutments and buttresses are laid upon a concrete floor from 8 to 12 in. thick. On culverts with a waterway up to 10 ft. wide, a concrete cover, 6 to 11 in. thick, with steel rods about 1½ in. from the lower face of the concrete, is used. For wider openings, up to 26 ft., flat concrete beams, 3 ft. on centers, 14 in. or more deep, 6 to 12 in. wide, and with two or more 1-in. twisted rods in the lower part of each beam, are used. The floor is of concrete, 4 or 5 in. thick, with ⅜-in. twisted rods embedded in it near the bottom. For openings larger than 26 ft., reinforced concrete arches are built, or a steel truss or girder bridge.

The crown of all roads is carried clear to the gutter. No drainage ditches are left parallel to and alongside the roadway.

No gutters are paved at the time a road is built. If the surface water cannot be diverted to prevent gullying, so much of the gutter as gullies is paved. Common field or bank stone is used for this purpose, laid on a bed of gravel, 6 to 7 in. deep. Ordinarily the pavement is 3 ft. wide with a pitch of 1 in. to the foot next the roadway, and 1 ft. wide with a pitch of 1 ft. to the foot on the sidewalk side. Large stones are used in the gutter and run in rows with their long dimensions parallel to the road. All other stones are laid at right angles to the road. All stones are laid on edge, adjacent stones touching each other.

No especial precautions are taken in preparing a foundation on porous soils, the surfacing material being placed directly upon them.

When the road traverses clay or other non-porous soil, extra precaution is taken to secure a solid foundation by the use of gravel, stone or some other material not acted upon by frost. This foundation may be of telfording, it may be a **V** center drain already described, or it may be a thick coating of sand or gravel. The treatment in all cases depends upon the character of the soil and traffic, the location of the material and the cost of putting it in place. On heavy traffic roads, the foundation is laid to the full width of the surfacing. On other roads it is from 10 to 12 ft. wide. When a telford foundation is laid, it is generally used in connection with side drains. The subgrade is shaped and rolled, and covered with a coating of gravel 2 to 3 in. thick, on which the telfording is placed. The telfording is of angular stones laid with their broadest edge down, with the long dimensions across the road, as close together as their shapes will permit. The spaces between the tops of these stones are filled with smaller, wedge-shaped stone, point downward, driven firmly into place. The surface of coarse stone is thoroughly rolled with a steam roller before the surfacing is put on.

Narrow trenches from the edge of the telfording to the gutters and filled with stone, are placed at intervals to insure thorough drainage.

In cases where there is a scarcity of stone, and a convenient supply of stony gravel, the gravel is used as a foundation. It is spread to a depth of 12 to 18 in., the thickness depending upon the quality of the soil in the subgrade. After thoroughly rolling, the surfacing is spread over the gravel. If stone and gravel are scarce then sand is used as a substitute. The loss of bearing-up power due to freezing and thawing of non-porous soils, when used to support a permanent road surfacing, is a fact well known to road builders.

The dividing line between porous and non-porous soils is not well defined. In Massachusetts State work, soils that contain 25% of a material that passes through a screen with 10 000 meshes to the square inch is treated as non-porous, and the foundation is specially considered. As the percentage of the above fines in the soil increases, extra precaution is taken with the drainage, and the foundation is increased in thickness.

With soils containing less than 25% of material that passes a 10 000-mesh screen, the surfacing of broken stone or gravel is laid directly upon it, the standard 6-in. Macadam being spread on soils with from 25 to 20% of the fines, and the thickness decreased to the minimum when laid on good gravel. Gravel is used on all roads where the traffic is not heavy and the gravel of good quality and sufficiently near to be placed at a reasonable price.

In some instances, the gravel is screened into two sizes, and the coarse is placed on the graded and rolled subgrade, and this is covered by the fine. No stone larger than 2½ in. is used. All gravel is spread from the carts or dumping boards. Roads of this kind are better if steam rolled. Screening is not necessary with some gravels, more particularly with that kind containing but few or no large stones. The objectionably large stones are raked ahead and left directly on the subgrade. Some of these gravels are benefited by rolling, but most of them are not. The road is carefully watched, and the ruts that may form are eliminated by raking the loose gravel into them, until the surface becomes hard and smooth. The number of rakings and the length of time required to compact the gravel depend upon the volume of traffic and character of gravel. Generally, the longer time a gravel takes to become thoroughly compacted, the longer time will the road last.

The same precautions are taken to secure good drainage and firm foundations on a gravel road as on a broken-stone road.

The general theory of broken-stone roads has already been given. The thin road is placed over a gravel or coarse sandy subgrades, and this thickness is increased to the standard, which is 6 in. in the middle and 5 in. on the sides when the soil contains 20% of material that passes a 10 000-mesh screen. No change in thickness is made until the above fines approach 25%, and then the standard thickness is used on whatever foundation may be laid. The thickness referred to is after rolling, and is 67% of the thickness of the loose stone, the total shrinkage of the loose broken stone being one-third.

In selecting stone for breaking, to be used in building stone roads, traffic and cost of placing are the controlling factors. On heavy traffic roads only hard trap rock is used, whether it is to be found in the locality, or has to be shipped in by rail. On roads with medium traffic, the cost of maintenance as well as the first cost of stone is considered, and the higher grade rock may be used, although the cost is materially greater. On all other roads, the best available local stone is used, if it has any value for such purposes. Soft lime rocks have not been used on any State roads. But little quartzite has been used on account of brittleness, and because where quartzite is found a better stone is also found, which can be as cheaply used. On many roads local stone which is not of first-class quality is used as a bottom course, with a 3-in. covering of trap rock. For several years past screenings from local stone have been used on this kind of road instead of trap rock. All stone is broken by stone breakers. The plants for breaking consist of a crusher, engine, elevator and raised bins, allowing the stone to pass from the crusher to the cart without rehandling. There are six large private plants, each of which can furnish from 200 to 500 tons of broken stone per day, and which can be shipped by rail to any part of the State.

All stone passes from the crusher to a revolving screen placed over the bins. This screen has three sections with meshes of 2½ in., 1½ in., and ½ in., respectively. Experiments on State roads furnish conclusive evidence that a road built of screened stone wears better and retains a smooth surface much longer than one built of unscreened stone. The stones that pass a 2½-in. mesh are placed on the carefully graded and rolled subgrade, or upon the foundation course, whatever that may be made of. This course is thoroughly rolled and evened up with stone of the same size. On the 2½-in. stone is placed the stone that passes the 1½-in. mesh. These are thoroughly rolled and evened up with stone of the same size. The screenings, or that part of the product of the crusher passing a ½-in. mesh, are used as a surface or binding course. They are spread on to cover the next lower course well, thoroughly watered and rolled until the mud flushes to the surface. The watering is continued until the rolling is finished. All rolling is done by steam rollers, the edges being rolled first, and gradually working toward the center. When feasible, the shoulder is rolled with the stone. On country roads of light traffic, the broken-stone surfacing is laid to a width of 12 ft.; with an increased traffic, this width is made 15 ft. The grading and shaping is carried out to give a width of 18 ft. on the 12-ft. and 21 ft. on the 15-ft. stone roadway. On roads approaching villages, having a fairly large volume of traffic, the shoulders, for a width of 3 ft. on each side of the broken-stone roadway, are made of gravel, placed to a depth of 4 in. or more, the depth being regulated by the character of the soil. In the absence of good available gravel, and on roads with a still larger volume of traffic, the broken stone is increased to a width of 18, 21 or 24 ft. When the roadway is laid over loose sand, the broken stone is given a width of 15 ft., as the shearing effect on the edge of the finished way tends to decrease the width.

The width of the taking, or right-of-way, varies from 30 to 80 ft. Within this right-of-way is the roadway, space for a sidewalk on each side, and, in certain instances, a single, or double street-railway track.

The crown of the roadway consists of two planes, joined by a curved line in the center. The pitch is ¾ in. to the foot on rural roads, 1 in. to the foot on hills, and ½ in. to the foot in village streets.

On all State roads, proper attention has been given to the roadside. It has been cleared of unsightly things, and left so as to be easily cared for without destroying its characteristic features. Trees are being set out alongside all State roads where needed, and where the different telephone, light, and street-railway wires will permit.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON
HIGHWAY CONSTRUCTION.

By Messrs. R. J. Thomas, Halbert P. Gillette, W. R. Hillyer,
Henry Manley, Oberlin Smith, B. C. Donham,
James Collier, B. Cole, H. K. Barrows,
E. Purnell Hooley and James Owen.

R. J. Thomas, M. Inst. C. E., Aylesbury, England.* (By letter.) Mr. Thomas. —The writer wishes to make known the English practice on one or two points raised by Mr. Owen. On pages 107 and 108 the principles of Macadam are compared unfavourably with those of Telford, and a point is made in favour of the latter, where drainage is necessary.

It must not be overlooked that Macadam based his entire principle of using small stone to the exclusion of what, in England, is called a pitched foundation (*i. e.*, large stones laid by hand, properly filled as to interstices with smaller wedge-shaped stones) upon the effective and thorough under-drainage of the soil upon which the small stone (or, as now described, Macadam) was to rest, and it is found in practice that the more complete and extensive the execution of this essential portion of Macadam's system, the greater the protection against frost-bound foundations and consequent upheavals during thaws.

The writer, during 20 years spent in maintaining some 450 miles of main roads on all classes of foundations, and sustaining exceptionally heavy traffic a few miles out of London—the larger proportion of which has been constructed on the Macadam principle—has not found any difficulty in securing stability in all weathers

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* County Surveyor of Buckinghamshire.

Mr. Thomas. where due care has been taken to secure adequate subdrainage, in some cases, it is true, at considerable expense.

The excessively hard frosts experienced in the United States would inevitably add to the expense of similar subdrainage by necessitating increased depth and possibly a double tier of drains; but, making due allowance for this, the writer thinks that satisfactory results would be obtained were Macadam's complete system adopted experimentally, and that, in regions where good stone for foundations was not obtainable except from a considerable distance and at considerable cost, there would be a marked reduction in construction outlay.

Telford abandoned his particular system of foundation stones in more than one instance where, strangely enough, Macadam's requirement of a well-drained subsoil was obtainable. The writer, a few years ago, had to remodel a length of the old Shrewsbury and Holyhead Road constructed under Telford's personal supervision, and found that many miles of it, where it traversed light, loamy, well-drained country, was entirely devoid of pitched-stone foundation.

It is not customary in English practice to use foreign material for what Mr. Owen calls "packing," and the writer questions seriously the introduction of such adjuncts to effective consolidation.

When constructing a Macadam road, the writer spreads the stone in layers of sufficient thickness to provide, when rolled, a one-stone thick coating, rolls it dry until all settlements and depressions are exposed, filled, and again rolled, adds water copiously, and rolls again whilst the water is continuously swept across the road until there is produced, by pressure from the road foundation, sufficient binding material—added to the small stone pulverised during the dry rolling—to effect complete and compact conglomeration, the excess slurry or mud being well swept off.

Additional coatings are added until a finished thickness of 6 or 8 in. is obtained, and this, on a thoroughly dry and well-underdrained soil foundation stands any traffic and continues to do so until the stone crust is worn down to 1 in.

The less foreign binding material or packing used, the greater the density, as the stones naturally fit closer together, and their smaller interstices are filled largely with minute particles of similar material, which must necessarily prolong the complete cohesion of the entire fabric forming the road.

Roads constructed in this way undoubtedly resist the disturbing effect of traffic in dry weather far better than those treated too liberally with binding or packing; and the writer believes that in the United States, in spite of the difficulties created by greater climatic variations, it would be found that a similar result would be obtained, possibly to a lesser degree, but yet to an advantageous prolonging of the life of sound surface. **Mr. Thomas.**

It is obviously of paramount importance to make the surface of a road as impervious to moisture as possible, so that the subsoil can be kept dry and independent of frost and thaw, and the writer is strongly of opinion that this can best be effected by the exclusion of binding material, especially that of an absorbent or friable character. It is daily becoming more evident that the growth of fast high-powered motor-car traffic in England (the writer has seen at times as many as 700 traversing one road in 12 hours) is an active agent in disturbing and loosening the most carefully consolidated Macadam surfaces, as the suction produced by small-sized, rapidly revolving, pneumatic-tired wheels is sufficient to extract particles of small stone from the road surface, in addition to stirring up clouds of dust, which in minor degree is of use on exposed portions of road. Having to face this difficulty, the writer has experimented with (*a*) materials for laying the dust; (*b*) binding the surface of Macadam to counteract the suction; and (*c*) laying entirely fresh material of great cohesive non-absorbent quality.

a.—The beneficial effects of dust-laying experiments were slight, costly, and transient.

b.—The tar painting of a Macadam surface was quite satisfactory for a period of six weeks, when it required a second painting. The first dressing cost 2 cents per sq. yd., the second 1½ cents.

c.—In 1903, the writer laid a 3-in. coating of iron furnace slag, impregnated with oil of tar under a patent process, on the London and Bath Main Road, and he must admit that, up to date, the surface is smooth, the section sound, and evidence of wear *nil,* whilst there is an entire absence of dust.

The writer believes that roads, especially those traversed by motor traffic, will have to be faced with some such cohesive non-absorbent material.

Mr. Gillette. Halbert P. Gillette, M. Am. Soc. C. E., New York City. (By letter.)—The writer notes that, in common with many writers on the subject of road construction, Mr. Owen has shown a tendency to designate by a class name the rocks that he regards as being fit or unfit for a given use. The word, granite, for example, is used as if it applies to a combination of minerals practically invariable as to chemical and physical properties. Granite, however, is a term which, as commonly used, conveys no definite idea to the lithologist. Not only do its feldspathic constituents vary chemically, but the size of the crystals and their relative percentage in the mass vary in even greater degree. In a word, granite is a term only a little less vague than the word "trap," which, it has been truly said, "covers a multitude of ignorances."

Mr. Gillette. Nor is the road-builder justified in using the terms, limestone or sandstone, as if they applied only to materials of definite chemical composition. The sandstone of Upper New Jersey, for example, is probably as poor a material for a Macadam road surface as can be found in that State; but, on the other hand, the Medina sandstone of New York is an excellent material for Macadam. The limestone of the Pennsylvania coal measures is apt to be so friable as to make a muddy road surface. This friability is doubtless due to large percentages of argillaceous impurities. On the other hand, limestone from Middle New York is admirably adapted for road metal.

It has seemed worth while to call attention to these facts, which, although apparently self-evident, are often ignored by those who attempt to lay down broad rules governing the choice of road materials. Moreover, Mr. Owen, while not directly challenging the methods of rock testing now in vogue, implies that something must be wrong with any system of testing which places a limestone as high on the list as a trap. It is not the purpose of the writer to defend the methods of testing used by the U. S. Department of Agriculture, but it is his wish to emphasize the importance of freeing ourselves from the bondage of names. The granite of one range of mountains is not the granite of another range; the sandstone of one county is not necessarily the sandstone of another county, even though that county be but a few miles distant.

Passing from rocks to the best method of converting rock into road metal, the writer wishes to take exception to the statement that machine-crushed rock makes a poorer Macadam than hand-broken stone. In the first place, all statements bearing upon this subject are, so far as the writer knows, merely a matter of opinion. No one appears to have laid sections of the same road using hand-broken stone on one section and machine-crushed stone on an adjoining section. Until this is done, and until accurate records are kept of the relative wear, who can safely say which class of construction is economically the best? The writer believes the crushed stone road, as laid to-day, either in New York State or in Massachusetts, is a more durable road than any Macadam ever built. He bases this belief in part upon the fact that the so-called cubical fragments used in any hand-made road do not remain cubical during the "coming-down" process. The wagon wheels make marbles of a great percentage of the stones before enough dust is formed to act as a binder—at least this has been his observation wherever he has seen country roads made in the good old way. Codrington, moreover, gives physical analyses of Macadam roads built by the Macadam method, showing, if the writer remembers correctly, that fully 50% of the compacted Macadam was stone dust and mud.

Mr. Gillette.

Neither theoretically nor practically is there any good reason why hand-broken stone should continue to be spoken of as preferable to the rock-crusher product; but, on the other hand, the writer considers the rock-crusher product actually better, because a large percentage is fine screenings, useful as a binder.

The writer would ask Mr. Owen whether he has any evidence to prove that rock broken with a gyratory crusher is less serviceable than rock broken with a jaw crusher. The statement has often been made that the jaw crusher is to be preferred, but, although the writer has examined with care the product of both kinds of crusher from the same kind of rock, he has not been able to detect the alleged advantage of the jaw-crusher product. Incidentally, he would add that it is the practice in many of the large plants to do the coarse crushing with gyratory crushers and the finer crushing with jaw crushers.

Passing from the metal to the use of it on the road, there bids fair to be a diversity of opinion as to the best practice for some time to come. The writer agrees with Mr. Owen in believing that all stone should be screened, but his reasons for screening are somewhat different. Screening is essential to secure a perfect mixture of coarse stone and screenings in the road; for, if no attempt is made to screen the crushed rock, the fine pieces will tend to segregate by remaining at the top of the pile, while the larger pieces will roll down to the outer edges. This holds true even when the material is delivered into bins, as it always should be; but, were it not so, the jarring of the wagon or car conveying the metal would jig the fine stuff to the bottom of the wagon.

Mr. Owen is a consistent advocate of the frost theory of road disintegration, but the writer has not changed his belief in its fallacy since he put himself on record regarding the subject some three or four years ago. His experience and observation have covered road work in the "frost belt," and thus far each year has served but to strengthen his belief in the sufficiency of Macadam without a Telford foundation, and also in shallow, broad ditches designed merely to carry surface waters and leave about 1 ft. of dry soil beneath the Macadam. The writer has been fortunate in being able to examine a good part of the road mileage built under Mr. Owen's designs, and is convinced that less stone, used entirely in the form of Macadam, would have served fully as well in the spring, "when the frost is coming out of the ground."

Mr. Owen says that frost is probably destructive of the bond of Macadam. The writer recalls a 12-in. Macadam laid in a village street where there was no effective drainage for several hundred feet. Indeed, conditions were so bad in this respect, that, when a number of test-holes were dug through the Macadam, water ascended

Mr. Gillette. in each hole to within 6 in. of the Macadam surface. This was late in the fall, yet neither during the long cold winter that followed, nor in the following spring, was there any sign of heaving of the Macadam or destruction of its bond. The writer takes it that, where frost does occasionally serve to effect a breaking up of the smooth surface of Macadam, the result is not due to the heaving action of the frost so much as to the unequal settlement under heavy loads. This unequal settlement is due to the unequal rapidity with which the frozen earth thaws under the Macadam, resulting in yielding spots of thawed earth adjacent to unyielding spots of frozen earth. A Macadam that is too thin to distribute the wheel-load over a sufficient area of the unfrozen earth will necessarily yield; but a thicker Macadam will not yield at all. The instance just cited bears out the latter statement, and the writer has in mind a number of cases where yielding of thin Macadam has occurred in the spring. He is not so sure, however, that the frost has even then been the cause of yielding; for the snow in the ditches and the slush upon the Macadam were sufficient to dam back the water, and cause a saturation of the earth beneath the Macadam, which would not have occurred at any other time than in the spring.

Reverting to the subject of Telford foundations as being a necessity in "the frost belt," attention should be called to the fact that the Massachusetts Highway Commission has abandoned the use of Telford, and that the New York State Engineer has found it desirable to use Telford only in rare instances.

Mr. Owen speaks of the necessity of using "packing" where the metal is trap, and of the desirability of using no "packing" where the metal is limestone. If by "packing" is meant the earth that is so commonly used in place of stone screenings in Upper New Jersey, it should not be used, as it is, with any rock. Trap-rock screenings should preferably be used to fill the voids first, then a little limestone dust, or fine sand will serve to fill the minute voids in the trap screenings and effect a binding. Limestone, as a rule, needs no earth "packing" at all, since most varieties yield a sufficient percentage of screenings in crushing. There are limestones, however, that do not yield enough binder in crushing, so that binder must be imported or fine sand or loam used. Where this must be done, the writer always prefers to bind the lower course with the sand or loam entirely, reserving the limestone screenings as a binder for the upper wearing course. This gives a strong Macadam base and a clean Macadam wearing coat.

The writer agrees with Mr. Owen with regard to the intermittent method of repairs, and would add that few men in the United States in charge of road maintenance know the cheapest and quickest way of repairing large areas of Macadam. Only the other day he saw a gang of some thirty laborers in upper New York City breaking up an old Macadam crust, using picks for the purpose. With a 12-ton steam roller provided with picks, and a team of horses following with a heavy harrow, it would have been an easy matter to resurface a greater area in a given time than these thirty men were resurfacing.

In an article on the "Macadam Pavements of Albion, N. Y.,"* the writer described the methods and cost of resurfacing Macadam by using a steam roller followed by a harrow, a sketch of which appears in the article. The cost of resurfacing was as follows:

	Cents per square yard.
Roller and engineman at $1 per hr. for picking....	0.5
" " " " " " " " re-rolling..	0.5
Sprinkling with cart at $0.40 per hr..............	0.2
Harrowing, team and driver at $0.30 per hr.......	0.3
Total	1.5

At this rate a Macadam road, 16 ft. wide and 1 mile long, can be resurfaced for $140; and, as such resurfacing has not been required oftener than once in five years on the main street leading into Albion, a village of 5 000 inhabitants, in a rural district, it is safe to put the labor cost of resurfacing at less than $30 per mile per annum. At the time that these estimates were made the cost of new metal (Medina sandstone) had been about $60 per mile per year, the wear having been about ⅓ in. per year over the whole road area. This, it should be added, was a street carrying a far greater traffic than is common on most main roads in the United States; and it should also be noted that the road metal is a sandstone presumably not as durable as the Hudson River traps.

Finally, the writer wishes to endorse Mr. Owen's appeal to the railroads for better rates on crushed stone. Personally, he has seldom had any difficulty in securing special rates on Macadam metal. Illinois has often been cited as a large State in the center of which no suitable road metal is to be found. The writer believes, however, that material, suitable for the lower course of Macadam, exists, and he knows that Illinois railways have made such low rates that broken stone has been exported to neighboring States for road work. Engineers who go to local traffic agents to secure a quotation on freight rates will invariably meet with disappointment, and, as a rule, give up the idea of importing stone from any considerable distance. The thing to do is to "go higher up." Railway officials in the higher positions are, almost without exception, such broad-minded men that they can see far enough into the future to per-

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* *Engineering News*, September 19th, 1901.

Mr. Gillette. ceive the advantage of having Macadam roads as feeders to their lines. Indeed, one railway has gone so far as to put a special train at the disposal of the U. S. Department of Agriculture, to be used as a "good-roads train."

The trouble lies not with the railway officials, but with road engineers who fail to press their just demands for better rates on road metal. When they begin concerted action, they will, the writer predicts, be surprised and gratified at the results; and we shall find that those who oppose Macadam road construction on the ground that no rock is available, will have to admit that non-availability is a phrase synonymous with lack of effort to discover ways and means.

Mr. Hillyer. W. R. Hillyer, M. Am. Soc. C. E., Port Richmond, N. Y.—Referring to remarks made by Mr. Owen concerning the successful use, under certain conditions, of materials not ordinarily considered as appropriate for road construction, the speaker desires to cite an instance in which a material, generally considered very unfit, was used to good advantage in the Borough of Richmond, New York City. Constructing a short piece of road in the grounds of the Richmond County Country Club, a Telford base was formed of soapstone (serpentine), which was plentiful in that region—and the only native stone that was plentiful—and, upon this Telford, a top of broken trap rock and trap-rock screenings was placed, the result being that for the past five years or more a good road has been maintained. The reason for trying this experiment was that any stone other than soapstone had to be brought in by railroad to a station distant ½ mile from the work and hauled up heavy grades to a height of from 150 to 200 ft. Of course, this heavy hauling had to be done with the trap rock. The soapstone, which is a substance entirely unfit for the upper course and surfacing material of the road, because of its softness and its disintegration when wet, has proven a trustworthy foundation when kept dry and protected from the grinding action of traffic by the trap-rock covering.

Mr. Manley. Henry Manley, M. Am. Soc. C. E., Boston, Mass.—The basic idea of Telford, as the speaker understands it, was not necessarily the use of broken stone of large size under the road, but that a base sufficient to carry the traffic should be provided. Now, if Nature has provided the base, there is no occasion for doing it over again. That seems to account somewhat for the difference of opinion expressed by Messrs. Owen and McClintock. The base is necessary in all cases; it may be secured by furnishing a layer of solid material, or it may be furnished by the subsoil, if that subsoil happens to be of such a character that it will exclude water and remain solid and substantial under the traffic, with the addition of a wearing surface.

Under the conditions which are imposed in cities, the Telford

Mr. Manley.

foundation may be omitted much more generally than in country roads, for the reason that the entire width of the street is practically impervious to water, and usually none can soak into the base from the outside. If the base be not of the best character naturally, it will usually carry any traffic that should be imposed upon Macadam roads. The practical difficulty is to preserve the base in good condition long enough to cover it with the wearing surface of Macadam. This can be done by taking advantage of the weather and by using water sparingly during the first part of the rolling.

There is one thing that the speaker would be glad to hear discussed. Mr. Owen's recommendation is that broken stone should not exceed 2 in. in diameter. Mr. McClintock says 2½ in. in diameter. Now, that means a great difference in the size of the stone. To compare one with the other, we must cube the given dimension. An extra ½ in. in the diameter of a stone does not sound very much, but, in this case, it means doubling the size of the stone, and the speaker thinks that 2 in. is better than 2½ in.

There is another element in the problem that must be taken into account in most places, and that is that the average superintendent who has the care of the roads will wear them, if the political conditions are such as to require it, just as long as they will last, and when the 3 in. are worn out he is down right on his Telford. If you have 6 in. of Macadam, it will wear longer, and when it is worn out there is nothing left, but if the foundation was there to begin with, just as good as the Telford, nothing has been lost, as the wearing surface must be replaced in either case.

Asphalt blocks are not laid in Boston at present, but we did lay quite a number of them on a bed of sand. They stood perfectly well until worn out, but the length of wear under a pretty heavy city traffic was not sufficient to warrant laying more, that is, they were too expensive. They wore down until they were, perhaps, not over 2 in. thick, and then began to break up, but the sand held them perfectly until they were worn out, *viz.,* for five or six years.

The speaker has been disappointed that the subject of pavements in cities has not been discussed more fully. There is no object for which city money is expended in which engineering science is less considered than in the matter of street pavements. There are enormous amounts of money expended in pavements and in repairs on the same. It has been stated that, next to the railroad industry, it is the largest and most expensive engineering industry in the country. Probably politics has something to do with it, but, as a matter of fact, there has been less scientific examination into the ways and means of economical methods of paving city streets than in any engineering subject of equal magnitude. Any railroad man can tell you, to the smallest fraction, the cost of everything that

Mr. Manley. goes toward the building and maintaining of railroads, but few city men can tell you intelligently the cost of many of the things used in their work. They may know the price per yard paid the contractor, but the actual cost is something that has not been studied and reported upon carefully in any case on a large scale. There is a plentiful lack of recorded experiments in cost and durability of street pavements and their maintenance.

No city known to the speaker has classified its streets in order of their importance, or of the traffic upon them, as every State that has commenced to improve its country roads has done.

Traction experiments upon different varieties of pavement are few in number, and the results, as published, have not been well confirmed by repetition.

The building of country roads is a subject of instruction in most or all technical schools, but city pavements receive much less attention. The United States Government gives aid and comfort to country road building through the Road Inquiry Office, but pavements are outside the scope of its inquiries.

Progress in city pavements has been made, not through the initiative of the cities, but through the promotion of companies using patented methods and materials, and it has become a general practice to let by contract for a term of years, not only the original construction, but also the maintenance of the more modern and improved pavements in all large cities.

Mr. Smith. OBERLIN SMITH, M. AM. SOC. C. E., Bridgeton, N. J.—Is it common throughout the West to use the old plank road? Many years ago, in Ohio, the most notable thing in the way of roads was the plank road. It was the pride of the whole country. The planks were some 3 in. thick and 12 or 15 in. wide, by about 8 or 9 ft. long, laid crosswise on sleepers. They were good at first, but the ends and sides curled up, and after a while the planks became loosened. Such roads were much better than none, because the only substitute then was the corduroy road, made of logs, from 4 to 8 in. in diameter. It is proper to ask whether there are any corduroy roads, or any plank roads, now being made throughout the West; if so, how are they built?

Can any one tell whether there are many roads, supposed to be good, made of asphalt blocks on sand only, with no other foundation? In one town in New Jersey there have been a few miles of such roads laid with the sand heavily rolled. The blocks are some 6 in. thick, and, perhaps, 4 by 8 in. in plan, laid directly on the sand; and they are doing very well. They seem to stay level, and neither frost nor travel affects them.

Another question: To what extent are ordinary hard red brick used? There seem to be many pavements of such brick in St.

Louis, but it is generally supposed that they are not used very much in America, although favored to a great extent in France and Germany. Mr. Smith.

If gumbo is good, and is made of the same material, why does it not pay to go to the extra expense of moulding it and have a clean flat pavement? On what kind of foundation are such bricks laid?

An important appeal to road engineers, which pertains in general to roads, and especially to city streets, should be in favor of noiselessness. People are perfectly willing to have granite blocks substituted for cobble stones or mud, but engineers do not seem to realize that the nerve-torturing racket on such roads is a very great detriment to the health and comfort of the citizen. There is a great difference in the comfort of living upon streets paved respectively with asphalt or granite blocks. Asphalt, either in sheet or block, is the most noiseless material for pavements.

It is rumored that rubber is being tried in England, but this material is doubtless too expensive. There is a great movement in progress (though young as yet) to get rid of city noises—the noise of the wagon, the tramping of horses' feet on hard pavements, the banging loads of iron, etc., as well as the noise of street vendors' cries and hand organs—but there will never be an ideal city until a pavement of some material like rubber is obtained—unless, indeed, nothing but horseless vehicles with rubber tires are used.

B. C. Donham, Assoc. M. Am. Soc. C. E., Seoul, Korea.—The speaker has had no experience with corduroy roads in a civilized country, but it may be interesting to know that it is a common form of native highway construction in Korea. The most valuable lands are those where water is available for rice cultivation. The result is that irrigation is practiced to a great extent, and there are large areas of rice fields where the water stands during almost the entire year. The roads through these districts are often so muddy as to be nearly impassible without special treatment. Round pieces as straight as possible and from 4 to 5 in. in diameter are chosen. These pieces are laid in the mud about 1 in. apart and with as even a surface as possible. This makes a firm, though very rough, road and fairly suitable to the light traffic of that country. The speaker has been told that they often wear ten years before there is much decay. He knows that a road so built near his house in 1900 was in very good condition in 1904 and appears good for four years more. Mr. Donham.

James Collier, Esq., Denver, Colo.*—For the past two years, the City of Denver, Colo., through its Board of Public Works, has been laying a wearing surface on its residential streets with no other base than the natural material in the street. This class of work has been designated as "surfacing," as the courts have ruled that Mr. Collier.

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* Asst. Engr., Dept. of Public Works.

Mr. Collier. the word, "paving," must not be used unless the average thickness exceeds 3 in.

The residential streets of the city comprise over 1 200 miles of roadways, a considerable portion of which are of a very heavy clay and become almost impassible after severe storms. A demand was made by the property owners for a cheap improvement of these roadways, and the Board, after several experiments, selected, as most satisfactory, a surfacing of disintegrated granite, a rough gravel reduced from a solid granite formation by natural decomposition.

The material, which is found in many localities in the Rocky Mountains, has been obtained so far mainly from Sherman Hill, Wyo., 140 miles distant, and from the South Platte Cañon, Colorado, 30 miles distant. In both cases, the material has been dug by a steam shovel from the hill and passed over a ¼-in. screen directly into the cars. The average size of this granite is about that of roofers' gravel, pieces of more than 1½ in. in diameter being thrown out or broken on the street.

The roadway is prepared for the material by being finished with a blade machine, sprinkled, and rolled with a steam roller to make a compact base, the center of the roadway being graded approximately 9 in. above the gutter for a 30-ft. roadway and 12 in. for a 40-ft. roadway, the gutter being uniformly 9 in. below the top of the curbing.

The disintegrated granite is measured in the wagons, only wagons having a uniform size being allowed on the work. The number of loads required to make the proper thickness in each block is calculated in advance, allowance being made for shrinkage and rolling. The material is distributed to an average depth of from 2 to 3 in., according to the terms of the contract, the larger part of the material being placed in the center of the street. The granite is deposited in piles of one load each at even distances, spread by a blade machine, and raked by hand to a finished surface. It is then sprinkled sufficiently to moisten the base so as to make a bond when rolled. The rolling which follows is continued until the surface is compact. The raking, sprinkling and rolling are repeated, where necessary, after a period of a week or two, during which time the surface has hardened sufficiently. The streets are seldom closed to traffic during construction.

Gutters have been constructed on all streets in the surfacing districts which have heavy grades, the width being determined by the rate of grade and the area drained, averaging about 3 ft., but being wider at the foot of the slope than at the top. In one contract, the gutters were sub-graded to a depth of 4 in. and filled with disintegrated granite passed over a ½-in. screen. Hot asphaltum tar was then poured in until all the voids were filled. Then the fine screenings were spread on top, and the whole was rolled with a hand roller, forming a close, tough mass. In another contract, large stone spalls were used, and the voids were filled with disintegrated granite, the rolling being done with the rest of the roadway. The cost of the spall gutter was less than one-half the cost of the asphaltum tar. Both have given satisfaction. Mr. Collier.

No cross-walks have been found necessary. The districts so far established have a complete system of storm sewers, so no box drains are required. The distintegrated granite surfacing sheds water readily, and, in the dry climate of Denver, is sufficient to protect its base. It remains firm after severe storms. The cost for the district is assessed against the property owners in the district. Five districts have been completed with surfacing, comprising over 40 miles of roadways, at an average contract price of about 22 cents per sq. yd.

Surfacing District No. 1 contains 130 000 sq. yd., and the contract was let for 19 cents per square yd., of an average thickness of 2½ in., the specifications calling for a thickness of 3 in. in the center of the street and 2 in. at the sides.

Surfacing District No. 2 contained 145 000 sq. yd., and the contract was let for 22 cents per sq. yd., of an average thickness of 3 in., 3½ in the center of the street and 2½ in. on the sides. The cost to the property owners, including gutters, where necessary, engineering, inspection, advertising and collection, averaged 57 cents per front foot.

Surfacing Districts Nos. 1 and 2 were completed in about 30 days each, averaging 4 500 sq. yd. per day.

The disintegrated granite is of a reddish color, and has a pleasing effect to the eye.

The City Council let a contract for 4 000 cu. yd. of disintegrated granite at $2.50 per cu. yd., delivered on the street, to be used during 1904 for repairs and improvements in all completed districts. It was spread about 1 in. thick along the center of the streets, sprinkled and rolled. No patching has been found necessary, so that the entire amount appropriated for maintenance has been used to increase the thickness of the surface. During July and August, the unshaded portions of the streets require heavy sprinkling on account of the heat and lack of humidity. The short length of time this material has been in use does not permit of any definite conclusions as to its durability, but so far as can be determined, it will prove satisfactory for residence streets, especially in view of its low original cost and cheapness of maintenance.

B. Cole, Assoc. M. Am. Soc. C. E., Tecumseh, Ala.—Within the last few months, the State of Illinois has begun to enforce the law Mr. Cole.

Mr. Cole. against contracting the labor of convicts in the penal institutions. This law allows the penitentiaries, however, to manufacture and to furnish, as far as they are able, for public institutions, such materials as they require.

Within the grounds of the Chester Penitentiary, there lies a large body of very hard limestone, known in the geological series as the Chester Limestone. The authorities are now able to furnish crushed limestone to cities and counties for their needs f. o. b. cars at Chester, but so far as the speaker knows, its use has been confined to the construction of Granitoid sidewalks and street construction in the smaller cities. A large Gate's crusher was installed some years ago, but has never been worked to its full capacity.

Mr. Barrows. H. K. Barrows, Assoc. M. Am. Soc. C. E., Bangor, Me.—Two points occur to the speaker which could, perhaps, be discussed with interest: First, as to how bitulithic pavement compares with other pavements as regards the factor of slipperiness, and upon how steep a grade it has been used to advantage. The attention of the speaker was brought to this by the fact that Bowdoin Street in the City of Boston has this form of pavement, and has also quite a steep grade. It is reported by people living in that vicinity that heavy traffic avoids this street, owing to the tendency of horses to slip and fall. From what the speaker has seen of this pavement in other places, it would seem to compare favorably with other forms in this respect, but it would be interesting to hear how it is considered by parties who have used it.

The second point relates to the amount of shrinkage of Macadam during the process of rolling. There are very few data upon this subject, and what exist seem to be considerably at variance. From the figures given by Mr. Owen, there would apparently be 80% of shrinkage, if correctly computed. This corresponds pretty closely to many figures given, particularly to those recently published in regard to some Macadam roads in the City of Cambridge, Mass. The fact is, however, that under different conditions these figures vary to a marked extent. The speaker was connected with some Macadam road construction in the City of Newton, Mass., a few years ago, and careful records were kept of the stone used. Results showed a shrinkage in rolling of about 62 per cent. This low figure could, perhaps, be attributed to the weight of the heavy rollers used, and to a very hard and compact subgrade. In fact, in compiling data on this subject, the condition of subgrade, the manner and amount of rolling and the kind of stone used must be alike in order to make a comparison of results possible.

Mr. Hooley. E. Purnell Hooley, Assoc. M. Inst. C. E., Nottingham, England. (By letter.)—The writer has read Mr. Owen's paper with the greatest interest and must congratulate him on the most excellent work that he is carrying out. In a general way, he is adopting a

Mr. Hooley.

more substantial foundation than is usual for the construction of English country roads, but, with such a magnificent material so close at hand and evidently produced at such a cheap rate, this is not to be wondered at, for undoubtedly if he is erring at all, it is on the side of stability.

With regard to his method of surfacing, the writer is convinced he will find, as English engineers have found, that it is absolutely necessary to use a different method of construction. With the advent of light locomotives, as well as the heavy road locomotive, in addition to the almost hourly advance of locomobiles, or as we call them, motors, it is absolutely necessary to form the surface so that the whole knits together in one perfect mass, and this cannot be carried out properly by the ordinary system of steam rolling and watering. That roads have been maintained in the past without steam rolling is well known, but no modern engineer with the slightest regard for his reputation would now attempt big works without the free use of steam rollers. But steam rollers alone will not make a good road, and, with this in view, the writer has introduced into the county for which he is the County Surveyor, a system for the construction of roads that is water-proof and will not allow disintegration by locomobiles. With fast travelling vehicles over uncemented joined surfaces, disintegration must take place, and, as this increases, dust and mud form on the road surface to the annoyance of everyone, and at the expense of those who have to bear the cost of maintenance, and the writer would strongly recommend to American engineers the adoption of a better method of forming the road surface than the ordinary binding with water and fine material, which only disintegrates, as he has stated, and forms mud.

In America, it seems to the writer that there is not the heavy traffic that engineers in England are called upon to deal with, but the day is coming when country roads in the United States will have to bear a heavy traffic similar to that which we now have in England.

In some parts of England, scavenging, or cleaning, amounts to quite half the cost of maintenance, and, by a system of water-proofing the roads, this could be reduced to a figure nearer 5 than 50% of the actual cost. But the difficulty is in finding the material which makes the best water-proofing and, after many experiments, the writer has come to the conclusion that a mixture of common gas tar, pitch, and resin alone will do that which is needful. By a process which he has adopted, a good road material can be saturated with the oil of this mixture, and the result is such a road that the public in every district cry out for its extension.

Mr. Owen.

JAMES OWEN, M. AM. SOC. C. E., Newark, N. J. (By letter.)—The writer is gratified with one result of his efforts, and that is the endorsement of his main idea with regard to road construction, *viz.*, Mr. Owen. that there can be no positive definite practice for the country at large. This premise being granted, the realization of good road construction can be obtained by aggregating the varied experience in different localities, and making intelligent deductions therefrom. The writer regrets somewhat that his suggestion as to the use of inferior materials in certain localities did not receive more criticism or discussion, but the experience of Mr. Hillyer in Staten Island, in using soapstone foundation, is a case in point. As to the question of foundations, the discussion still shows that good roads can be made without them, but it also shows that in certain localities a good foundation is necessary.

The Denver experience of Mr. Collier with 3-in. roads is instructive, although it must be remembered that the frost problem in that locality is not serious, and that the construction, as outlined, was not properly an engineering problem, but was determined upon for legal reasons. The writer can endorse the condition of the roads in that city from personal observation, and he also acknowledges that he has constructed miles of road in the same way, but he does not encourage the practice. The fact, as cited by Mr. Thomas, that Telford himself, in cases, abandoned the foundation in parts of his construction, endorses the writer's proposition of broad conception in road work.

In the use of packing, the discussion brings forth the varied practice in vogue. Mr. Thomas says that it is not customary to use it in England, and gives it as his opinion that material other than stone dust is detrimental. The writer suggests that climatic conditions differ in the United States, and while theoretically the pure stone has more wearing capacity, a long spell of dry weather breaks up a road to such a degree that a continuous application of screenings is a very costly procedure.

On this same subject of packing, Mr. Gillette first says that earth should not be used at all with trap rock, but that he does use it with limestone. As this practice is the reverse of that adopted by the writer, it is interesting, and merely emphasizes the fact of possible endless variation, with good results, but it is none the less important to emphasize the necessity of judgment in the use of extraneous material which may jeopardize results.

As to the selection and classification of material, the facts brought out in the discussion are merely supplemental to the paper, and give additional information that is desirable. The nomenclature of the different rocks, as currently fixed, of course gives no definite idea of their availability for road construction, and it is undoubtedly true that the traps, granites, limestones and sandstones are so diverse in their individual adaptability that it is not out of order to suggest some systematic classification of material

Mr. Owen.

for road purposes only, this classification to be dependent upon the results of use as well as laboratory analyses.

As to the size of stone, the character and density of travel are the factors which govern the selection, the extremes being a heavily traveled street with the necessary 2½-in. stone, and a private driveway with a ¾-in. covering. The general average, from 1½ to 1¾ in., seems to be the best for highway service when trap is used; of course, with softer stone, a larger size may be consistently adopted.

Whether hand-broken stone, or stone broken by a machine with either rotary or direct-acting jaws, makes a material difference, the writer has no figures to show, but only gives his opinion as the results of observation in the extensive use of the different kinds, of course, still maintaining the ideal of a cubical character. In his particular district, there are always from 100 to 150 convicts breaking stone by hand, which is used on the adjoining roads, and it is an undoubted fact that the rotary crusher does not yield an output of stone of so cubical a character as that from the direct-acting crusher, or as the stone broken by hand.

There is one point connected with this part of road construction, however, that has so far received but slight attention, and that is brought in by the statement of Mr. Gillette that the so-called cubical fragments used in a hand-made road do not remain cubical, but are worn round during the coming-down process. This is undoubtedly true, but to the writer's mind this does not prove that the homogeneousness of the stone amalgam, if it may be so called, is destroyed, and two instances are recalled: First, his observation of a piece of old-fashioned hand broken wagon-road Macadam laid in London forty years ago, which was taken up previous to the construction of the intercepting sewer. The Macadam was wedged off in sheets 10 to 12 ft. square and about 1 ft. thick, and was as solid as any up-to-date concrete made of Portland cement. Secondly, his experience in 1904 in relaying a piece of Telford that had a hole broken through it about 1 ft. in diameter, showing the settlement of earth over a water pipe laid fourteen years ago. In this case only the homogeneity of the stone, broken by machinery and packed with Jersey loam, prevented earlier collapse. Argument on these two facts is needless, except as a dissertation on refinements about which the Engineering Profession can indulge with but little profit. The road problem in the United States is to use the cheapest material at hand in an intelligent manner, and to obtain the most economical results in final maintenance, the incidental cost of construction being a very small factor in the problem.

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INTERNATIONAL ENGINEERING CONGRESS,

1904.

ARTIFICIAL WATERWAYS.

Congress Paper No. 84.

ARTIFICIAL WATERWAYS IN GREAT BRITAIN.

By W. Henry Hunter, M. Inst. C. E., Chief Engineer,
Manchester Ship Canal, Manchester, England.

Congress Paper No. 85.

THE IMPROVEMENT OF THREE HOLLAND SHIP CANALS.

By L. F. E. van Hoogenhuyze and J. A. de Lint, Assistant
Engineers, Royal Waterstaatcorps, Ter Neuzen, Holland.

Congress Paper No. 86.

INLAND NAVIGATION IN FRANCE.

By A. Chargúéraud, Ingénieur en Chef des Ponts et Chaussées,
Ingénieur en Chef de la Navigation de la Marne,
Paris, France.

Congress Paper No. 87.

ARTIFICIAL WATERWAYS IN THE UNITED STATES.

By William L. Sibert, M. Am. Soc. C. E., Maj., Corps of Engrs.,
U. S. A., Pittsburg, Pa., U. S. A.

Discussion of the Subject by

E. L. Corthell, New York City, U. S. A.
L. A. Huergo, Buenos Aires, Argentine Republic.
D. and C. Stevenson, Edinburgh, Scotland.
B. F. Thomas, Louisa, Ky., U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
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ARTIFICIAL WATERWAYS.

ARTIFICIAL WATERWAYS IN GREAT BRITAIN.

By W. Henry Hunter, M. Inst. C. E.*

Artificial Waterways, whether in the form of canals proper, of canalized rivers, or of combinations of the two, may be divided generally into three classes, *viz.:*

Class *A.*—Isthmian canals,
" *B.*—Primary canals,
" *C.*—Secondary canals.

The respective functions of each class are:

A.—To enable sea-going vessels to pass from sea to sea, over a greater or lesser width of what would have been intervening and obstructive land, had not human artifice and effort availed for the removal of the obstruction;

B.—To enable sea-going vessels to pass from the coast line and to penetrate into the interior of the country of their destination;

C.—To enable barges and other vessels of small size to convey from the over-sea steamer to the various parts of the district, which the terminal docks, whether in the harbour on the coast line or of the Primary canal, serve as a port, the commodities or goods imported into that district; and conversely, to carry from the parts of the district at which they originate, to the terminal docks, commodities and goods which are intended for export therefrom.

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* Chief Engineer to the Manchester Ship Canal, England.

In the convenient though somewhat inaccurate phraseology of the day, waterways of the Primary class are described generally as ship canals, and those of the Secondary class as barge canals.

It must be regretfully admitted that in Great Britain during the last ten years, the development of engineering practice in any of the three classes of Artificial Waterways presents but a limited field for review, for though, under the pressure brought about by the great increase of size in ocean steamers which has taken place in the decade, much has been done on the coast line for the improvement and extension of harbours and docks, little has been accomplished in the construction of highways over which the ocean steamer can convey her cargoes at small cost, or by means of which those cargoes may be water borne to or from her side.

So far as the formation of canals of the *A* class is concerned, nothing whatever has been done in the period under consideration; indeed, nothing has been done in respect to the construction of an inter-oceanic waterway in Great Britain since 1823, when the Caledonian Canal was opened for traffic, after Thomas Telford, whose name will ever be held in honour, and whose memory will always be venerated where Engineers meet, had joined together a chain of fresh-water lakes in the "Great Caledonian Glen," and had thus made a way over which the ships of the day were able to pass from the Atlantic Ocean to the North Sea *via* the Firth of Lorne on the one hand, and the Moray Firth on the other. The Caledonian Canal remains as a monument of the genius and the determination of the great man who designed and constructed it, but, fitted as it is, with locks of 170 by 40 ft., and furnished with a ruling depth of 18 ft., the canal is obsolete as a marine highway.

At the present time indications are not wanting that the termination of this lengthened period of inactivity has come into view, as stress of circumstance and exigency of modern competition has once more forced to the front the project for the construction of an Isthmian canal, which will be like unto the Caledonian Canal, in that (*a*) it is proposed that it should be formed on Scottish land, and (*b*) it will link together the Atlantic Ocean and the North Sea, through the Firth of Clyde on the west, and the Firth of Forth on the east.

If the proposed route of this important waterway be regarded from the point of view of international commerce, the conclusion that the location is about 170 miles to the northward of the ideal line appears to be irresistible, as it can hardly be doubted that the sum of geographical considerations combine with the trend of commercial developments to indicate that the true ideal line for an Isthmian canal in Great Britain would be not from the Clyde to the Forth, but from the Mersey to the Humber.

But the ideal is seldom found to lie within the limits of practical politics; and seeing that in Great Britain at any rate the present period is of an intermediary character, and that, on the one hand, the tide of economic enterprise has ebbed to so low a level that private capitalists cannot be induced to provide the funds required for the construction of public works of great magnitude; while, on the other, the pressure of public opinion has not yet become sufficiently pronounced to compel the Administration and the Legislature to undertake such construction at the national cost; it is necessary, in order to promote development of any sort, that projects which, if less perfect, are more feasible, should be pursued, rather than proposals which, though more ideally perfect, are *ad interim* impracticable.

Two alternative lines of construction have been suggested for the Scottish waterway, with in each case one or more variants.

In the first line (*i. e.*, that which has been before the public for the greater length of time) which is advocated by Messrs. D. and C. Stevenson, of Edinburgh, it is proposed that Loch Long, which is an arm of the Firth of Clyde, and which for all practical purposes forms part of the Atlantic Ocean, should be utilized as the first stage of the maritime highway, of which highway Loch Lomond would furnish the second stage. The two Lochs would be connected at Tarbet by a cutting of about 1¾ miles in length, furnished with locks by means of which the water level in Loch Lomond (which is 22 ft. above mean sea level) would be maintained, not only throughout Loch Lomond, but also throughout the whole length of the canal to the locks near Alloa upon the River Forth. (Fig. 1.)

In the variants of this proposal suggestions are offered that the sea-to-sea traffic should proceed further up the Clyde before turning to the northward. (*a*) To a point almost abreast of Greenock, and from thence through a cutting about 4½ miles in length (passing through high lands and including a tunnel 1¾ miles long) with locks as before, to Arden on the southwesterly shore of Loch Lomond; (*b*) to a point on the Clyde still further inland, just below Dumbarton, from whence a cutting, with locks as before, would be formed in the Leven Valley until the southern extremity of Loch Lomond is reached.

The comparative lengths of the proposed line and of the two variants thereof are as follows:

1.—Mouth of Loch Long to east side of Loch Lomond *via* Tarbet, 28 miles;

2.—Variant (*a*) *via* Arden to same point, 14 miles;

3.—Variant (*b*) *via* Dumbarton to same point, 20½ miles.

In comparing these lengths Mr. D. A. Stevenson has observed:*

"The Arden route is therefore the shortest, but it would be the most expensive, owing to a length of tunnel of 1¾ miles, which could not be overcome by open cutting, as it passes under land about 300 ft. in height. The Dumbarton route is shorter than the Tarbet route by about 7½ miles, but as the Dumbarton route involves five miles additional canal, where vessels could only go about five miles an hour, and six miles of the Clyde, where the speed will probably be restricted to about eight miles an hour, the time occupied by the journey either way will be about the same. In steaming up Loch Lomond and also down Loch Long, vessels may go at full speed, and there would be no interruption from river traffic."

Leaving Loch Lomond, the canal would proceed inland along the low-lying valley of Endrick Water for about three miles, after which a length of about eight miles would be formed through high ground (of the eight miles 1¾ miles would have an elevation of 200 ft. above the mean level of the sea and over, with a maximum elevation of 236 ft.) from whence the canal would pass into the Valley of the Forth, the line lying to the northward of the towns of Kippen and Stirling, and traversing that valley for a length of about seventeen miles, would reach the entrance locks to be constructed above Alloa on the northerly side of the River Forth. These locks would form a terminus of the canal proper, and would, as hereinbefore described, retain the water in the canal at the level of that in Loch Lomond. From the locks aforesaid a tidal cut would be formed which would terminate at a point abreast of

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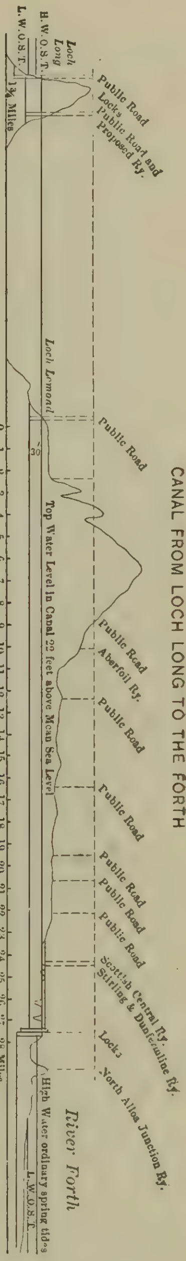
* "Notice regarding the Proposed Forth and Clyde Ship Canal," by D. A. Stevenson, B. Sc., F. R. S. E., M. Inst. C. E., Edinburgh.

CANAL FROM LOCH LONG TO THE FORTH



LONGITUDINAL SECTION
FIG. 2

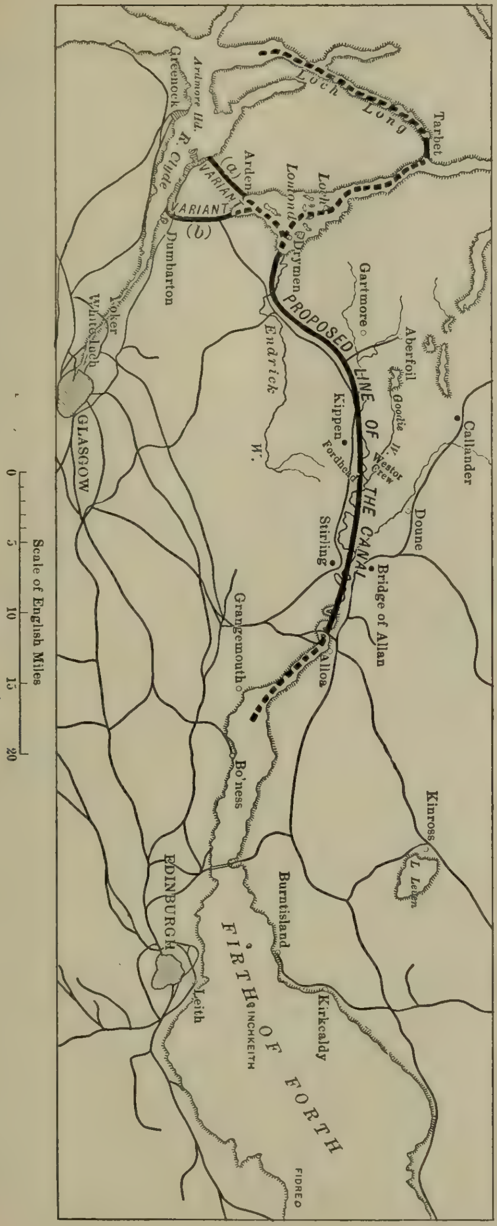


FIG. 1

Grangemouth, where the tidal range in the Forth is about 18 ft. at springs. (Fig. 2.)

The total length of the canal on this line would be 65¾ miles, which would be reduced by variant (*a*) to 51¾ miles, and by variant (*b*) to 58¼ miles.

It is proposed that the cuttings for the waterway should, like those of the Suez Canal as originally constructed, be formed as a single road, but that passing places should be provided at frequent intervals, and that the ruling depth should be 30 ft. The locks would be built in pairs, the larger lock of each pair being sufficient to pass a line-of-battle ship, or a merchant steamer of the largest class.

In connection with this part of the proposal it may be noted here that the S.S. *Baltic,* the most recent addition to the White Star fleet, and the largest vessel at present afloat, is 708 ft. between perpendiculars by 75½ ft. beam, and is marked for a draught of 34 ft., and that the Cunard Company is now building two new boats of which the dimensions will be 760 ft. in length by 88 ft. beam.

The approximate estimate of the cost of the work of the "National Canal," as this project is now termed, is £8 000 000.

In the alternative line, upon which it is proposed that the Forth and Clyde Canal should be constructed, and which is advocated by W. T. Douglass, M. Inst. C. E., the waterway would commence at Yoker, on the north bank of the River Clyde, between Dumbarton and Glasgow, and would terminate at Grangemouth (Fig. 3); the first suggestion being that the canal might be formed as a sea-level waterway throughout, and the variant (which Mr. Douglass favours, mainly on the ground of cost*) being that the canal should be constructed on the Yoker and Grangemouth line, but with impounding locks and varying levels. (Fig. 4.)

On the line suggested, the western or Clyde terminus of the canal would be formed in the new docks, now in course of construction by the Clyde Trustees, between Clydebank and Yoker, whence the waterway would pass through the valley of the River Kelvin to the small town of Kirkintilloch, from which it would follow the line of the existing Forth and Clyde barge canal to the Village of Bonny-

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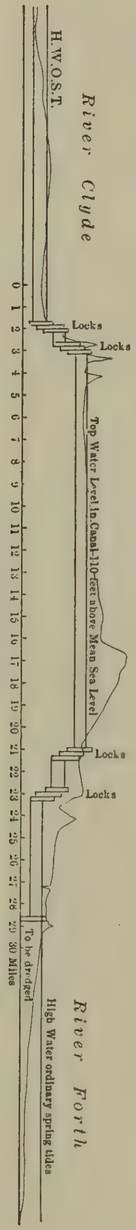
* Report on "Proposed Forth and Clyde Canal," by W. T. Douglass, M. Inst. C. E., Westminster, S. W.

CANAL FROM THE CLYDE TO THE FORTH


River Clyde
H.W.O.S.T.
Locks
Locks
Top Water Level in Canal 110 feet above Mean Sea Level
Locks
Locks
To be dredged
River Forth
High Water ordinary spring tides
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 Miles

LONGITUDINAL SECTION
FIG. 4

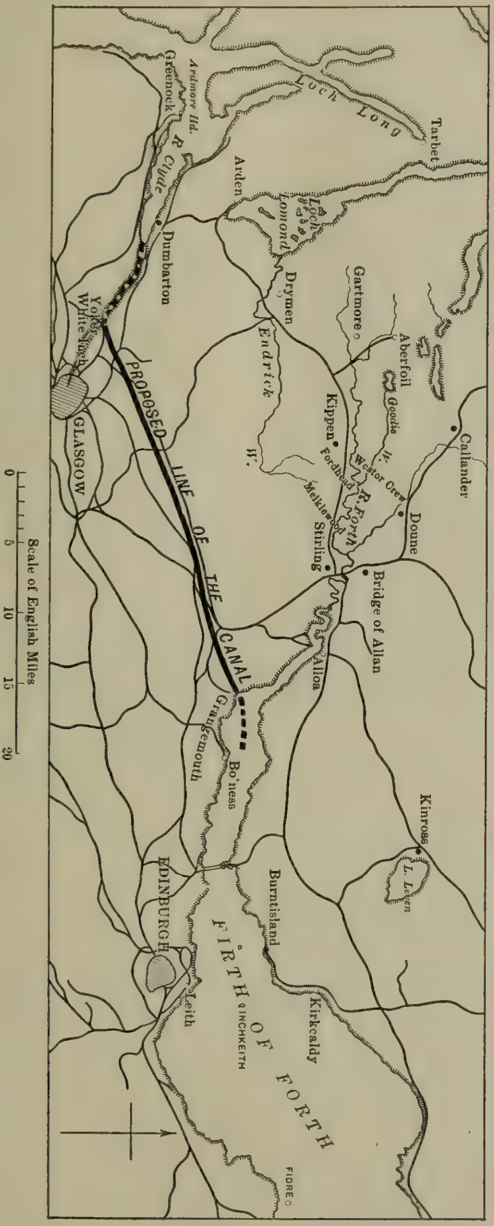


FIG. 3

bridge, and thence descend through the valley of the Carron to the eastern or Forth terminus of the canal, which would be formed at a point to the northward of the Carron piers at Grangemouth, on the southerly bank of the River Forth.

On this line the length of the canal would be slightly over 29½ miles. It is proposed that the summit level of the waterway should be 110 ft. above the mean level of the sea, that the length of the summit pond, the *bief de partage,* should be some 18½ miles, and that this level should be attained from the west by a chain of locks (a "Neptune's staircase," as Telford would have said), consisting of six steps, each step being formed of a group of two locks; and from the east by two similar chains of three steps each, divided by an intervening pond 1½ miles in length.

The standard section of the canal would have a width at the bottom of 130 ft. and a ruling depth of water of 30 ft., while the larger locks would be 750 ft. in length by 90 ft. in width, and 32 ft. in depth, the sills of the larger lock in each group being placed at a depth sufficient to allow of an increase in the ruling depth of the canal to 34 ft.

The cost of the construction of the canal, including the cost of the necessary railway and road deviations, the purchase of land, the payment of compensation to disturbed interests, and also including the cost of impounding embankments in the valleys of the Carron and Endrick, in order to form reservoirs therein for the purpose of ensuring an ample supply of water to the summit reach of the canal, is tentatively estimated at ten millions sterling (£10 000 000).

Apart from the commercial advantages of a waterway between the Forth and the Clyde, the canal would form a means of passage from sea to sea for ironclad line-of-battle ships, and it seems obvious, that, like the Kaiser Wilhelm Canal (which, *via* the River Elbe on the west and Kiel Haven on the east, connects the North Sea with the Baltic Sea), the strategic value of the Forth and Clyde Canal, regarded from the point of view of the defence of the British seas and the coast line of the British Isles, would be so great as to justify the expenditure required for its construction.

Recent experience in Eastern seas has afforded some indication of the amount of damage which might be occasioned to property and to shipping by the raids of a small fleet of speedy vessels, well armed, well equipped and handled with intrepid audacity, which might issue from the shelter of the land guns which protected it, just at the time deemed most opportune and favourable by a daring commander, who would choose his own course of destructive adventure and would take the risk of falling in with a more powerful fleet of the defending navy.

At such a time, having regard to the interests which are involved, minutes are valuable and hours invaluable, and it would be almost impossible to appraise rightly the advantages inherent to the existence of a maritime highway through which a squadron of reinforcement, hastening to intercept such a raiding fleet as that hereinbefore suggested, might pass without risk of hostile encounter or of fear of interruption by tempestuous weather, and through which the length of voyage of the squadron, whether from east to west, or from west to east, would be shortened by over 500 miles.

The matter may be regarded as of national rather than of international importance, but, from the point of view of national defence, it may be conceded that the advocates of the Forth and Clyde Canal have a *prima facie* case, for the contention that, in respect of such an undertaking, private enterprise might well be, and should be, reinforced by public support, or, in other words, by the practical assistance of His Majesty's Government in the operations required for the raising of the necessary capital, even to the extent of pledging the public credit to the payment of some return on the capital invested in the undertaking.

Apart from some such State aid, it is difficult to see how the scheme can be financed satisfactorily, particularly after the experience of the working of the Manchester Ship Canal, of which it may be truly asserted that such working has been and is the occasion of almost incalculable benefit, both direct and indirect, to all within the sphere of influence of the waterway, except the shareholders who provided the money for the inception of the project and the construction of the greater part of the undertaking.

The Manchester Ship Canal furnishes the most modern and complete example in Great Britain of a waterway of the Primary class, as the practical effect of the construction of the canal has been to indent the coast line so effectively that cargo steamers of a dead-weight capacity of over 10 000 tons are now regularly berthed in the Manchester Docks, 44 miles distant from the Rock Light at New Brighton, which marks the point at which the River Mersey passes the line of the Cheshire coast.

The first stage in the history of the canal was reached rather more than ten years ago, as the waterway was opened for traffic in 1894. All matters, therefore, relative to the design and construction of the works requisite for the attainment of that first stage are excluded from the scope of this paper.

It is anticipated that before another decade has expired the second stage in the history will have been reached; that is to say, that the revenue will be sufficient to yield some return on the whole of the capital invested in the undertaking, and that, as a consequence of the increase in revenue, the severe depreciation in the face value of the shares (due to the fact, to which allusion has already been made, that the canal has hitherto proved beneficial to everyone except its own shareholders) will have been overcome, and that the figures in the capital account of the company will much more nearly than at present represent the market value of the property, as well as the intrinsic value of the works and lands.

With this end in view, a sum of £1 433 595 has, since the opening of the canal for traffic, been expended in the development and improvement of the navigation and in the equipment of the docks and quays connected therewith. In addition to this large amount, a further sum of £316 000 was, in the year 1901, paid for additional lands for dock-extension purposes in Manchester. Upon these lands (which included the site of the Manchester Racecourse) new dock works are now in course of construction, the cost of which works will be £500 000.

As a further step in the development of the waterway, and as cognate to the increase of terminal facilities already effected or in progress, the canal company has in the recent session of Parliament (Session 1904) obtained powers for the increase of the depth of the canal from 26 to 28 ft. throughout. This deepening will render practicable the passage to Manchester of vessels of 12 000 tons dead-weight capacity, and will involve a further addition to capital cost of about £275 000.

Finally, so far as this paper is concerned (though, so far as the canal and the works correlative thereto are concerned, finality has not even come into view) as a site for a second new dock is available, it is in contemplation that the construction of such second new dock should be undertaken in the immediate future at an estimated cost of £500 000.

Summing up, therefore, the record of the development of the Manchester Ship Canal, as disclosed by the expenditure of capital on land, works and equipment, the figures stand as given on page 194.

The figures indicate the extent to which the undertaking has been extended and improved during the last decade, and illustrate the manner in which development renders further development necessary, and advancement calls unceasingly for advance.

As will be readily understood, by far the greater part of the expenditure incurred since the canal was opened for traffic has been devoted to the increase of the terminal facilities at the docks in Manchester, as it is clear that the measure of the capacity—the traffic capacity—of the waterway is, to a great extent, gauged by these terminal facilities, and that the question is not so much as to how many million tons of goods and merchandise may be conveyed along the canal per annum, as to how many million tons may be handled in the Manchester Docks, discharged, distributed, concentrated, loaded.

In the purchase of additional lands nearly the whole of the money was laid out in the acquisition of some 150 acres of land which, including the site of the Manchester Racecourse, was available for dock-extension purposes. Of the remaining sum of £1 433 595, already referred to, about £480 000 was expended in the completion and improvement of the waterway so as to render it more suitable and convenient for the passage of cargo vessels of large size—as already stated, steamers with a dead-weight capacity of 10 000 tons now navigate the Manchester Ship Canal—and over £953 000 was expended in the aforesaid increase of the terminal facilities.

One large occasion of expenditure at the terminal docks, amounting to nearly £200 000, has been the construction of railway lines and sidings; one result of the ten years' work and development having been to convert these terminal docks into what is tantamount to a huge waterside railway goods station, there not being a dock, basin, warehouse, shed or road included in the system which is not furnished with a line or lines of railway on each side thereof.

I.—Capital Cost (including cost of Terminal Docks at Manchester) on 1st January, 1894, when Canal was opened for traffic:		
Land	£1 200 846	
Works	9 246 093	
Equipment, Plant, &c.	416 268	
		£10 863 207
II.—Additional Capital Expenditure since 1st January, 1894:		
Land (including purchase of Manchester Racecourse).	£319 890	
Works	518 512	
Equipment, Plant, &c.	915 083	
		1 753 485
III.—Further Capital Expenditure on New Dock Works (Dock No. 9) now approaching completion:		
Land (included in II.)	—	
Works	£150 500	
Equipment, Plant, &c.	349 500	
		500 000
IV.—Estimated Cost of increasing depth of water in Canal and Docks from 26 to 28 ft., for which Parliamentary powers have been obtained:		
Land Works	£275 000	
		275 000
V.—Estimated Cost of construction of further New Dock Works (Dock No. 10), for which land has been purchased and capital powers have been obtained:		
Land (included in II.)	—	
Works Equipment, Plant, &c.	£500 000	
		500 000
	Total	£13 891 692

Another large item in the equipment expenditure, amounting to £400 000, has been due to the erection of transit sheds for the reception of goods, whether as import cargo discharged *ex* ship or as export cargo for loading into vessels. Experience has shown that, so far as the import trade at Manchester is concerned, for the handling of general cargo such as that which is borne by so large a proportion of the steamers engaged in the North Atlantic trade, some 5 000 sq. yd. of shed floor space are required for every 100 ft. of quay frontage in order to deal effectively with the huge quantities of merchandise carried by modern steamers, in the very limited time in which it is required that each vessel should be discharged. In order to provide this accommodation abreast of the berth in which the vessel may be moored, or, in other words, in order to avoid the necessity for moving the steamer while in process of discharge, the transit sheds at the Manchester Docks have been built with three, four and five floors—counting the ground floor in each case, and in the case of each of the four and five-floored sheds, counting also the flat roof, which is always available for the reception of cargo.

In addition to the cost of the transit sheds, the sum of nearly £60 000 has been expended in the erection of storage warehouses, and a further sum of £120 000 in the construction of a grain elevator of modern type with a storage capacity of 40 000 tons.

The remaining portion of the outlay on equipment has gone in dock roads (which have cost about £70 000), timber-storage grounds, hydraulic and electric installations, locomotives, wagons, cranes, capstans, engineering workshops, and in the almost numberless other appliances required for discharging, handling, sorting, storing or dispatching goods, in the rapid working which forms the characteristic feature of a modern dock system.

The new dock (Dock No. 9), now under construction, is of itself a work of considerable magnitude.

The basin will be over half a mile in length (2 700 ft.), and will have a width of 250 ft. between the walls. The water area of the dock will be 15½ acres, while the quay, road, railway and siding area will be 128½ acres.

The details of the dock construction present certain novel features upon which it is unnecessary to enlarge in this paper.

Operations for the construction of the works were begun in

August, 1902, and it is anticipated that the dock will be open for traffic in the middle of 1905.

On the southerly side of the dock a range of transit sheds, of which the dimensions are, for the reasons hereinbefore stated, exceptionally large, has been constructed. The range consists of five blocks of sheds, each block varying from 425 to 450 ft. in length, with a width over all of 110 ft. The area of floor space in the sheds will be about 22 acres.

The sheds are being constructed of ferro-concrete on the Hennebique system. Their superstruction was commenced on May 4th, 1903, and, as in the absence of any untoward circumstances the whole of the sheds will certainly be completed and equipped by May 31st, 1905, it may be claimed that the buildings will establish a record in shed construction, so far as time is concerned.

An additional grain elevator, of a similar capacity to that at present in use at the docks, but of a somewhat different type, will be erected at the easterly end of the dock.

The whole of the machinery for working the dock traffic, cranes, hoists, capstans, conveyors and grain elevator, will be operated by the electric current.

The large increase in the size of ocean steamers of the present day has rendered it necessary that the depth of the Manchester Ship Canal should be at once increased if the undertaking is to hold its own amidst the fierce competition for traffic which is now the normal condition of existence in the ports, harbours and waterways in Northern Europe.

Parliamentary powers having therefore been obtained, the operations required to increase the depth of the canal throughout its entire length from 26 to 28 ft. will be commenced forthwith. The total length of the waterway is 35 miles, of which 21 miles (from Eastham Locks to Latchford Locks) is subject to tidal influence.

In order to improve the conditions of navigation, as well as to obtain the additional depth required, it is intended that the height at which the water in that long reach is permanently impounded shall be raised from 9 ft. 6 in. above the mean level of the sea (the present level) to 11 ft. 6 in.; the headway of the different railway viaducts and road bridges which cross that length of the canal being sufficient to permit of this raising being effected.

When the waterway was constructed the sills of the various locks were placed 2 ft. below the bed of each respective length of the canal; it is intended, therefore, that in the remaining 14 miles (including the docks at Manchester) the increase in the depth should be obtained by rock blasting and dredging of the bed.

The operations for deepening, whether by the raising of the level of the water in the lower, or by the dredging of the bed in the upper length of the canal, will involve carrying out a large number of works, but it is anticipated that the whole will be completed by January 1st, 1907, and the waterway thus rendered suitable for the passage of steamers up to a dead-weight capacity of 12 000 tons.

The question may justly be asked: Has the policy, of which this great capital outlay has been the outcome, been vindicated by results?

The question is of no little importance to leaders of the people who guide the destinies of States, to political economists who collate "information which tells them how to improve the lot of their fellow-men," and to engineers to whom it is a necessity that it should be shown that capital sunk in well-devised public works, which are fitted to fulfill the purposes for which they were designed, is not capital lost; but at the present time the answer thereto must, to a great extent, depend upon the standpoint of the questioner, as the matter may be looked at (*a*) from the point of view of the community affected by the waterway, or, in other words, from the public point of view; and (*b*) from that of the shareholder in the company, or, again in other words, from that of the private individual who, in the first instance, found the money required for the formation of the great public highway.

From the public standpoint the answer to the question may be given in terms of no uncertain sound. The operation of the Manchester Ship Canal has directly or indirectly affected beneficially the whole of the greatest industrial district on the face of the earth; a district of which the present population does not fall far short of 10 000 000 persons; while in the more limited area of which the City of Manchester is the heart and center, many industries have been saved from extinction and many others from decline and ultimate decay.

In the years between 1880 and 1890 it was only too apparent that in Manchester and its environment of manufacturing towns, decadence was stamped upon almost every industry, and that all progress was arrested. One manufacturer after another moved his works to the seaboard, leaving disused factories, empty warehouses, and uninhabited dwellings to bear an ominously concurrent testimony to the inability of the community to maintain the preeminent position which had been the crown of the history of the eighteen centuries which intervened between the time when Roman soldiery builded near the River Irwell a fort, which they called "Mancunium," and the year 1853 when the Royal Charter, by which the ancient borough was raised into a city, was issued.

Now, not only has decline been arrested, and decay averted, but lines of new and vigorous growth have shot and are shooting out on every side, north, south, east, west, there is no exception, expansion is universal; old industries have been revived, and new industries have been introduced; the change is definite and impressive, and has been due solely to the effect and influence of the canal.

Mr. C. W. Macara, the President of the Federation of Master Cotton Spinners Associations, and ex-President of the Manchester Cotton Association, has said recently, and has given figures in support of his statement, "that the canal has, in reduction of the cost of conveyance of raw cotton and of goods manufactured therefrom, been worth at least £500 000 to the cotton trade alone." and Sir Frank Forbes Adam, C. I. E., the President of the Manchester Chamber of Commerce,* has also recently stated that "experience has proved that the existence and efficiency of the Manchester Ship Canal has become an absolute necessity for the maintenance of the trade of Manchester, and of the great industrial districts of which the city is the center."

Witnesses, of equal sincerity and almost equal standing to the two gentlemen quoted, might be multiplied, but the multiplication is unnecessary, as the testimony is undisputed and indisputable, none can be found who can deny that from the public standpoint the expenditure, great as it has been, has been followed by results by which it has been amply and more than amply, justified.

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* The Manchester Chamber of Commerce has 1 800 members who are representative of all the principal towns and trades for a radius of 20 miles around Manchester.

From the point of view of the private investor—the shareholder who put down his money to assist in providing the £8 000 000 of original share capital—it must be admitted that the answer to the question is of a markedly different character.

In the tenth* year of the history of the canal as a mercantile undertaking, the toll-paying traffic upon its waters amounted to 3 846 895 tons and the net revenue to £166 176.

The figures are considerable, yet are not a true measure of the benefit which has been rendered to the community served by the canal, or of the advantage which has accrued to the general trade of Great Britain owing to the working of the waterway, and due to the reduction of charges at other ports and on other routes of conveyance effected by such working; and many shareholders have, owing to this reduction, undoubtedly received an indirect though entirely satisfactory return on the money which they put into the enterprise; but many are not in this favourable position, as the only return which they can look for is in the form of dividend on their shares, and until the revenue has been considerably increased the obligations now standing before their shares in the form of mortgage debentures, etc., cannot be met, leaving the further increase of revenue, year by year, for division amongst them.

The increase will undoubtedly be secured, and the second stage in the history of the waterway, referred to in an earlier part of this paper, be reached, if the canal be kept abreast of the requirements of its trade, and if the terminal facilities required for the handling of its traffic be provided, and it is on this ground that it is claimed that even in the interest of the private shareholder the money expended, or to be expended, on the development of the undertaking is money well invested.

Turning to the class of Secondary canals, the effects of the misguided policy, which, in the earlier days of railway construction in England, permitted railway companies to acquire so many of the inland waterways of the country, are now being severely felt by British manufacturers, who, in the competitive struggle for the markets of the world in which they are engaged, are heavily handicapped by the high rates which they are called upon to pay, and which are so largely due to the lack of enterprise and effort which has left the inland waterways of Great Britain without improvement or development for so many years.

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* 1903. In 1894 the total toll-paying traffic was 925 659 tons.

So far as length is concerned, the inland waterways in England are by no means of inconsiderable extent. Mr. J. S. Jeans has epitomized their lengths as follows:*

Owned by Public Trusts	927¼	miles.
Independent Canals	1 445¼	"
Guaranteed and Owned by Railway Companies.	1 333	"
Derelict	118½	"
Ownership not known	36¾	"
Total	3 860¾	miles.

According to the latest Board of Trade Return on the subject, there were, in 1898, 2 768 miles of independent canals, with a traffic thereon of 33 348 573 tons per annum, out of which a net profit of £216 per mile was earned, and 1 138 miles of canals under railway control, with a traffic of 6 009 820 tons per annum, and a net profit of £40 per mile.

As in the case of the class of Isthmian canals, so in that of the class of Secondary inland canals, it is apparent that the long period of apathetic indifference to the value of the waterway as a competing route with the railway is passing away, and that an era of greater enterprise has been initiated.

On the Aire and Calder Navigation, extending from Leeds to Goole, and forming part of the network of canals and canalized rivers which covers and connects the manufacturing districts of Lancashire and Yorkshire, and which further forms an attenuated and meandering connection between the Mersey, on the west, and the Humber, on the east, extensive improvements have been and are being effected, under the auspices of Gerald Fitzgibbon, M. Inst. C. E., the Engineer to the Trustees.

Amongst other works, an important diversion of the River Aire is being carried out below Leeds, and a new junction canal, 6½ miles in length, which will connect the Knottingley and Goole Canal with the South Yorkshire Navigation, and so will open a new route to the South Yorkshire Coalfield, as well as provide direct water access from Goole to Doncaster and Sheffield, is being constructed at a cost of £250 000. The ruling depth of water in this Junction Canal is 9 ft. 6 in., while the locks are, in each case, 215 ft. in length by 22 ft. in width.

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* "Waterways and Water Transport," p. 54, E. & F. N. Spon, 1890.

Further, on the main line of the Navigation, the locks, which are 22 ft. in width, are being increased in length to 460 ft. (the extension of the locks being made 34 ft. in width), a sufficiently remarkable figure for an inland waterway, which has been adopted for the purpose of permitting a tug with a tow of twenty of the compartment boats (each carrying 37½ tons), in use on the Aire and Calder, to pass at one locking.

On the Grand Junction Canal, which forms a considerable part of the main line of waterways which connect the Mersey and Humber Valleys on the north with the Thames Valley on the south, quantities of material, averaging 16 000 tons per mile, have been removed by dredging operations from the sides and bed of the canal, with the result that the sectional area of the canal has been improved and the movement of craft thereon facilitated, while at Foxton, in Leicestershire, an inclined lift has been constructed, which has superseded a staircase of ten small locks, and has thereby effected a large saving in the consumption of water, and has also greatly accelerated the passage of traffic. The Foxton lift, which was designed and erected by Mr. Gordon Thomas, the Engineer to the Grand Junction, presents several features of novelty and interest, but as a detailed description of the lift, illustrated by plans, sections, etc., has been forwarded to St. Louis for exhibition at the Congress, it is not necessary to refer further to it here.

On the Shropshire Union Canal system, which extends from the Mersey to Wolverhampton with, *inter alia,* branches from Hurleston Junction (to the west of Crewe) and Norbury Junction (to the west of Stafford) which extend to Newtown in Montgomeryshire, and to the ancient City of Shrewsbury in Shropshire, respectively, operations of considerable importance have been carried out by G. R. Jebb, M. Inst. C. E., the Engineer to the Company, particularly at Ellesmere Port, which place was formerly situated on the southerly bank of the Mersey Estuary, but is now on the Manchester Ship Canal, and at which the Shropshire Union Canal system joins the ship canal.

Ellesmere Port, therefore, forms the northerly terminus of the Shropshire Union system and the junction of that system with the Manchester Ship Canal.

At Ellesmere Port, new quay walls, upwards of 2 000 ft. in length, and having depths of water of from 24 to 20 ft., have been constructed.

Upon the quays thus formed a six-floored grain warehouse, thoroughly equipped with elevators, band conveyors, etc., and having a storage capacity for 20 000 tons of grain has been erected, and in proximity to the elevator two large transit sheds have been constructed for the reception of general merchandise.

The quays have also been furnished with a high-level coal tip, and with a number of efficient hydraulic and steam cranes, capstans, etc., and have been connected with the lines of the London and North Western and Great Western Railways by a new branch railway and an extensive system of sidings.

Other works of importance in character have also been carried out at Ellesmere Port during the last ten years, the whole involving a capital expenditure of £250 000.

In other parts of the system, *i. e.,* in North and South Staffordshire, in the Potteries, etc., further improvements and additions have been completed, new goods stations equipped, wharves and basins have been constructed, new warehouses have been erected, and so forth.

On the Birmingham Canal, which connects Wolverhampton and Birmingham, and traverses South Staffordshire, East Worcestershire, and North Warwickshire, very considerable operations have been undertaken, also by Mr. Jebb. These operations have been to some extent in the nature of enlargements of the waterway, but have also been due to the necessity for reconstruction required owing to the fact that some 100 miles of the length of the Canal are subject to damage by subsidence caused by mining operations.

The water supply of the Birmingham Canal has also been greatly improved, the principal reservoir (Cannock Chase) having been enlarged in area from 150 to 230 acres, and in capacity from 575 to 775 million gallons; and modern triple-expansion pumping engines having been substituted at the various stations for the old Cornish engines.

The total capacity of the pumping engines on the Birmingham Canal (of which the length is 159 miles) now reaches nearly 100 million gallons per day of 24 hours.

In all the Midland Counties of England, where the strangling effect of the railway control of the waterways has been most severely felt, increasing restiveness on the part of the manufacturers and traders is becoming apparent, with the result that a scheme for a new and greatly improved water highway, from the Mersey to the Birmingham and Wolverhampton districts, which was advocated some years ago, but which appeared to die of inanition, has been revived and is now receiving serious consideration.

The scheme, as propounded by J. A. Saner, M. Inst. C. E., the Engineer to the River Weaver Navigation, is for a canal with a ruling depth of 6 ft. 6 in., with locks and lifts of 220 ft. by 22 ft. 6 in., which would be sufficient to pass a single self-propelled barge carrying 300 or 400 tons of cargo; or, alternatively, to pass a tug towing a train of nine of the narrow boats which are used in the Midland District, and which have special usefulness for small loads for individual works, as they supply an element of flexibility to the water-borne traffic.

It is proposed that the new waterway should begin by a junction with the Weaver Navigation, to the southward of the Town of Northwich, in the salt district of Cheshire. The Weaver is now an arm of the Manchester Ship Canal, is available for coasting vessels and barges drawing 10 ft. of water, and has locks 229 ft. in length by 42 ft. 8 in. in width. From the junction with the Weaver the main line of the waterway would pass southward, *via* Middlewich, Sandbach, Stoke-on-Trent (the center of the great pottery. district), and Lichfield, to Birmingham; the total length being 62 miles; while it is suggested that a junction should be formed on the main line, at a point between Stoke and Stafford, whence a branch canal would be carried through Stafford to Wolverhampton. The total distance from the junction with the Weaver to Wolverhampton would be 46 miles.

The profiles of both the main line and the branch present some difficulty, the contour of the ground in each case being such that it will be necessary for the level of the water to rise to 400 ft. or thereabouts, above that of the sea, to fall again to 300 ft., and then again to rise to 400 ft. in the case of the main line, and to 473 ft. in that of the branch. To overcome this difficulty, it is proposed that mechanical lifts should be largely used, and Mr. Saner has designed a special type of lift for the purpose, which he considers can be constructed and made to work effectively at a comparatively small cost.

Another proposal which has also strenuous and capable advocates has been put forward for a waterway from Birmingham to the sea *via* the River Severn and the Bristol Channel. The scheme would have local advantages, and would probably involve a smaller expenditure than that outlined above, but it would leave the great manufacturing area between Birmingham and the Mersey still without modern facilities for water transit, and would not be likely to lead the development of the new waterway into a general and national system of secondary canals, such as might be hoped for if the proposal for a waterway from the Mersey to Birmingham were carried into effect.

That the industries in the pottery district are in need of some effective competition which would reduce the rates of carriage on their goods, and thus enable them to compete on something like fair terms with their rivals abroad, the following incident will serve to show. The incident was narrated and vouched for by Sir William H. Bailey, at a public meeting in Manchester:*

A large pottery manufacturer in Tunstall had a considerable consignment of goods for London, the first portion of the consignment was sent in the ordinary way at the ordinary rate of 25s. per ton; the second portion, owing to a mistake made by a porter in labelling, was forwarded to New York; whence, the mistake having been discovered, the goods were sent to their London destination at a total rate of 15s. per ton, which would appear to imply that at the present day, if time is not of special importance, the most economical route from Tunstall to London, a direct distance of 148 miles, is *via* New York, or a distance of 6 750 miles.

Another project for the construction of an entirely new canal, which, though not of great extent, is of special interest as further indicating the revival of enterprise in respect of waterway construction in Great Britain, is just about to be commenced, as, in

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* *Manchester Guardian*, January 15th, 1904.

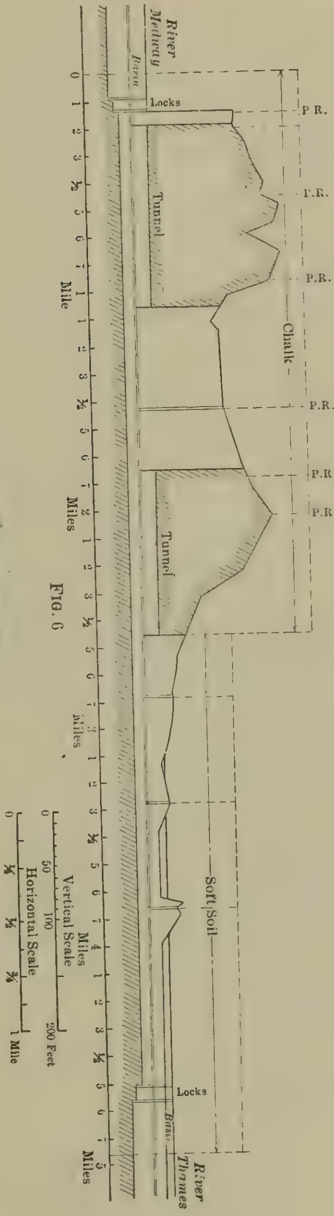
River Medway
Basin
Locks
Tunnel
Tunnel
P.R.
P.R.
P.R.
P.R.
P.R.
P.R.
Chalk
Soft Soil
Locks
Basin
River Thames
Mile
Miles
Miles
Miles
Vertical Scale
0
50
100
200 Feet
Horizontal Scale
0
¼
½
¾
1 Mile

FIG. 6

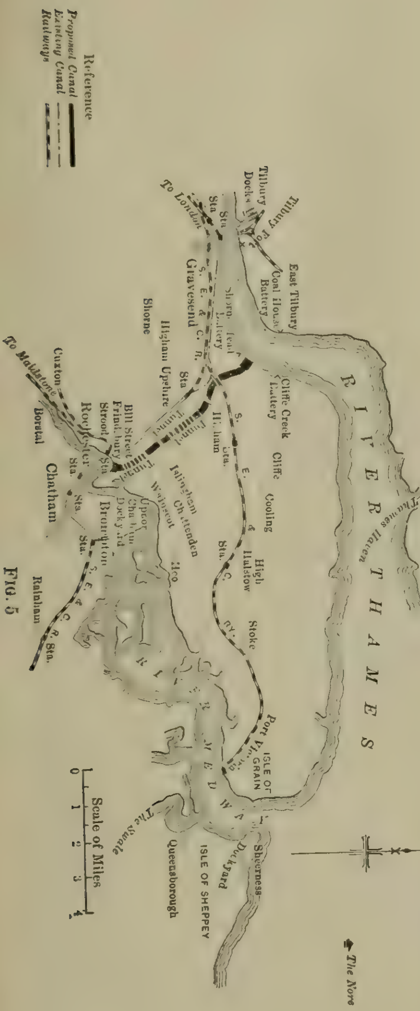
Reference
Proposed Canal
Existing Canal
Railways
To London
Tilbury Docks
Tilbury Fort
East Tilbury
Coal House Battery
Gravesend
Shorne
Higham Upchurch
Cliffe Creek Battery
Cliffe
Cooling
High Halstow
Stoke
RIVER THAMES
Thames Haven
Port Victoria
ISLE OF GRAIN
Sheerness
Dockyard
ISLE OF SHEPPEY
Queensborough
The Swale
The Nore
RIVER MEDWAY
To Maidstone
Cuxton
Borstal
Rochester
Strood
Frindsbury
Bill Street
Chatham
Brompton
Dockyard
Upnor
Frindsbury
Chattenden
Hoo
Rainham
S. E. & C. R.
Sta.
Scale of Miles
0
1
2
3
4

FIG. 5

the 1902 Session of Parliament, powers were obtained for the construction of a canal across the peninsula which separates the mouths of the Rivers Thames and Medway.

The canal is to commence on the north bank of the Medway, opposite the City of Rochester, and will terminate on the south shore of the Thames, about three miles below Gravesend. (Fig. 5.)

The total length of the canal will be 5 miles 6 chains, of which about 1¾ miles will be in tunnel. The headway in the tunnel will be 13 ft. 6 in., and the canal will have a bottom width of 27 ft. with a ruling depth of 10 feet. The only locks which will be required will be those at the two termini, where the rise and fall of the tide renders lock construction necessary. (Fig. 6.) The locks will be 300 ft. in length by 25 ft. in width.

Below each lock a tidal basin of 1 000 by 100 ft. will be constructed, in such manner as to enable barges, which are waiting for their turn to enter the canal, to lie in safety out of the way of the traffic.

A novel feature in the design of the waterway is a proposal to use upon it electric tugs for the haulage of the barges, which tugs would collect energy from an overhead wire, in the same manner as in electric tram cars with overhead equipment.

The canal will specially accommodate the barge and lighter traffic between the Medway and the upper portions of the Thames, which at present amounts to about 3 000 000 tons per annum, and which will largely increase after the construction of the canal, as such construction will shorten the distance now traversed by the barges (which round the Nore Light) by some 36 miles. It is also urged that the canal will have some value from the point of view of national defence, as it will furnish a direct and sheltered route for the conveyance of warlike stores from Woolwich Arsenal to Chatham Dockyard, as well as for the passage of torpedo boats and of the smaller class of torpedo destroyers.

The engineers for the canal, of which the estimated total cost is £250 000, are Messrs. Kincaid, Waller, and Manville, of Westminster.

It will appear from the foregoing pages that the record of the undertakings and operations which have been carried out in connection with British waterways during the last ten years may be summed up in terms of great brevity, as such undertakings and operations have comprised only works for the improvement and development of existing canals, no project for the construction of a new canal, or for the canalization of an untrained river, having been carried into execution. In this respect, enterprise has slumbered, and serious effort has been lacking, with the result that British interests have suffered, as the lack of up-to-date means of water transit, both for raw materials and manufactured products, has led to the imposition of rates for railway transit which are sensibly higher than those in vogue in the competitive lands which, in the Old World and in the New, lie to the eastward and to the westward of Great Britain.

Still, something has been done, and the revival of interest in proposals for the formation of new routes of water communication, and for the improvement of old and obsolete routes, is an indication of the fact that a turning has been reached in the long lane of indifference and supine neglect, which will, it may be hoped, lead to a new era of activity in the old home of canals and waterways.

A part of the mercantile community in England is, through the Chambers of Commerce and other existing organisations, now seeking to direct attention to the question of the nationalisation of the waterways in the United Kingdom, and is attempting the work required for the formation of a healthy public opinion upon that question.

There is no point in public policy of greater import than this at the present time. "Trade is now the one grand object of contention with Governments and people," says Mr. Frederic Greenwood, and none will say him nay, for as surely as in the days of our forefathers, nations struggled between themselves for tribute from others, now they struggle for trade with others, and the issues are vital—it is verily a struggle for existence. In such a struggle the best-equipped community must have the advantage and must succeed and survive, while the community which stands still where others are pressing forward must fall back, must fail, and commercially perish.

Experience has shown (1) that cheap and ready transport is an essential factor for the success of any trading community, and (2) that transport of such character can only be assured where waterways deliver the trader from the iron grip of monopoly. The statement, therefore, that waterways—operative and effective waterways—must form part of the equipment of any progressive nation which would hold its own in the struggle with its contemporaries, becomes simply the third term in a syllogism.

The creed of the individualist, in which it is an article of faith that what private enterprise has done in the past the same enterprise may do in the present or in the future, has become outworn, as the issues involved have grown and increased until they have gone beyond the scope of private enterprise, and beyond the power of private persons to deal with them with any hope of success; they are now matters of public interest, of national importance, and it is the duty of the community to accept the responsibility and to assume the burden; the question as to whether the community would be represented by the State as a whole, the National Government, or by the special districts interested acting through the medium of a Board appointed by and representative of the various units of local government, being left to be determined by the circumstances of each case and the conditions of each locality, with the certainty that whatever may be the answer to that particular question, the community, as a whole, may be assured that capital devoted to the formation and equipment of well-devised and honestly constructed systems of Artificial Waterways in industrial districts will prove to be a most remunerative investment, when the results which will accrue in the prosperity of these districts and in the well-being and comfort of their inhabitants are taken into consideration.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 85.

ARTIFICIAL WATERWAYS.

THE IMPROVEMENT OF THREE HOLLAND SHIP CANALS.

By L. F. E. van Hoogenhuyze and J. A. de Lint.*

The subject of the artificial waterways of the Netherlands is one upon which volumes might be written. Within the limits of this paper it is only possible to give a short description of the three most important waterways: The North Sea Canal, the canal from Ghent to Ter Neuzen, and the Merwede Canal. These have been constructed or improved within the last few years, and connect large cities with the sea or with a foreign country.

The writers wish to express their thanks to Messrs. Beyerman and Nelemans, Chief Engineer and Engineer of the Royal Waterstaatcorps at Utrecht and Ter Neuzen, for invaluable assistance.

The North Sea Canal.

The North Sea Canal is the highway of commerce from the North Sea to Amsterdam and is continued further eastward through the "Y" to the Zuyder Zee. In 1865 the works were begun, and on

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* Assistant Engineers, Royal Waterstaatcorps, Ter Neuzen, Holland.

November 1st, 1876, the canal was opened by H. M. William III. It was constructed by the Amsterdam Canal Company, but, owing to both technical and financial difficulties, an agreement was signed in 1881 by which the company transferred all its rights, properties and liabilities to the Government. Since then, many improvements have been carried out by the Government in order to make Amsterdam accessible to the largest vessels.

The new lock at Ymuiden, built between 1891 and 1895, certainly satisfies the most modern requirements and by the law of July 24th, 1899, the construction of works necessary to make the North Sea Canal capable of being safely navigated by vessels which can pass the new lock at Ymuiden was authorized: Length of vessel, 722 ft.; beam, 78 ft.; draft, 30½ ft. These works have been partly completed and will probably be finished before January 1st, 1907.

The Canal.—The canal, which traverses the "Y" (an inlet of the Zuyder Zee), has a uniform level and a length of 17.4 statute miles between the North Sea Locks and the Zuyder Zee Locks. As the canal also serves for inland navigation and the drainage of an important part of the country, several minor canals have been constructed opening into the North Sea Canal by locks and outlet sluices. The "polders" discharge their water into the canal by means of pumps. In ordinary circumstances this water flows at ebb-tide into the North Sea or into the Zuyder Zee. When the sea level is too high, the canal level is maintained by a pumping machine on the dam between the "Y" and the Zuyder Zee. This machine has two compound engines, each driving three paddle-wheels. The diameter of the wheels is 28 ft., and their width 10 ft. The capacity of this machine per 24 hours is: 770 000 000 gal. at a sea level of 4 ft. above C. L. (canal level), and 440 000 000 gal. at a sea level of 7½ to 8½ ft. above C. L.; 900 i. h. p. are required for 640 h. p. water lifted. However, the quantity of water discharged by the "polders" into the canal, under unfavourable circumstances, may amount to 990 000 000 gal. in 24 hours. Hence the capacity of this machine is not quite sufficient. The consumption of fuel is very low, amounting during the tests to 4½ lb. per hour and per h. p. water lifted. The drainage machine was ready for work in 1895, and cost $240 000.

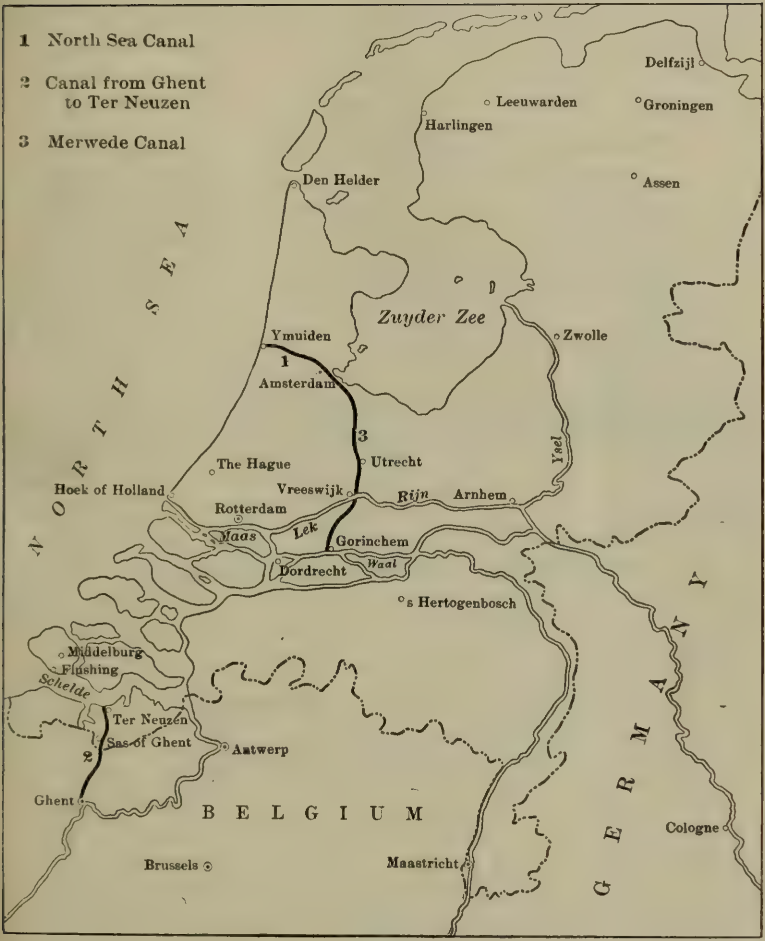

1 North Sea Canal
2 Canal from Ghent to Ter Neuzen
3 Merwede Canal
Delfzijl
Leeuwarden
Groningen
Harlingen
Den Helder
Assen
NORTH SEA
Zuyder Zee
Ymuiden
Zwolle
1
Amsterdam
3
Utrecht
Yssel
The Hague
Hoek of Holland
Vreeswijk
Rijn
Arnhem
Rotterdam
Maas
Lek
Gorinchem
Dordrecht
Waal
s Hertogenbosch
Middelburg
Flushing
Schelde
Ter Neuzen
Sas of Ghent
Antwerp
2
Ghent
BELGIUM
GERMANY
Cologne
Brussels
Maastricht

FIG. 7.

The width of the canal at the bottom is 118 ft.; and at water level 410 ft.; its depth is 28¼ ft., below C. L. As the greater part of the canal had, on both sides of the navigable channel, a submerged berm 98½ ft. wide, the canal banks did not require any artificial protection.

By the enlargement, which is in course of execution, the canal will have at all points a bottom width of 164 ft., a depth of 32⅙ ft. below C. L., with batters of 3:1, and a cross-section of 8 350 sq. ft. Except at some points, there will be left after the enlargement a submerged berm 10 to 27 ft. wide at 4 in. below C. L.

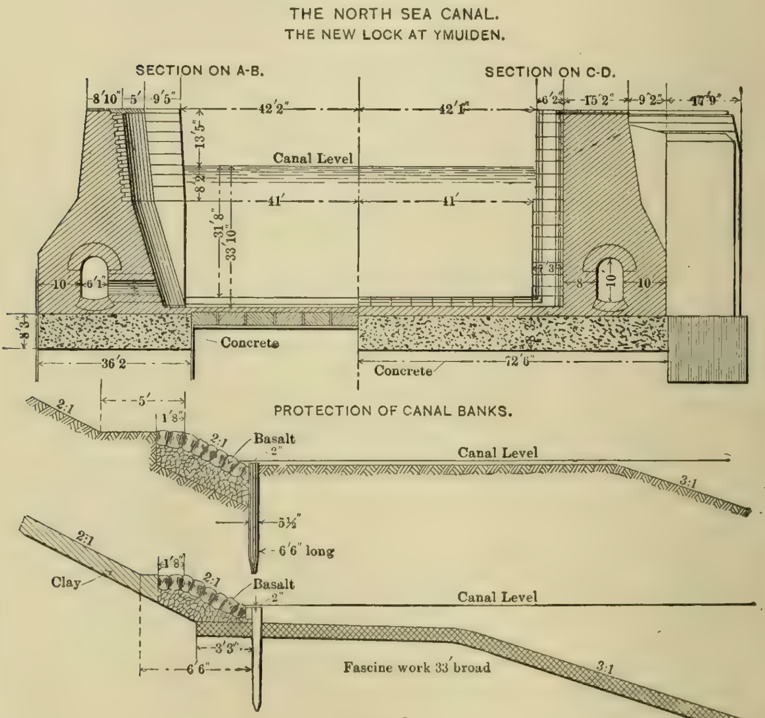


FIG. 8.

Along both sides, a bank protection will be made, reaching to 20 in. above C. L. and consisting of a stone pitching of basalt, 11 in. thick, on a layer of rubbish, 15 in. thick, supported at the foot by a compact row of pine piles 5½ ft. long and 5½ in. thick. In the section between Velsen and Ymuiden, where the banks consist of sand (of the dunes), this protection would be insufficient. Hence this part will be protected by a stone pitching of basalt on a layer of gravel supported at the foot by planking held in line by a row of pine piles, 6½ ft. long, and 3½ ft. apart. Below C. L. fascine work will be laid, 33 ft. wide. The cost per linear foot of the ordinary bank protection is $1.26, and of the protection with fascine work, $4.20.

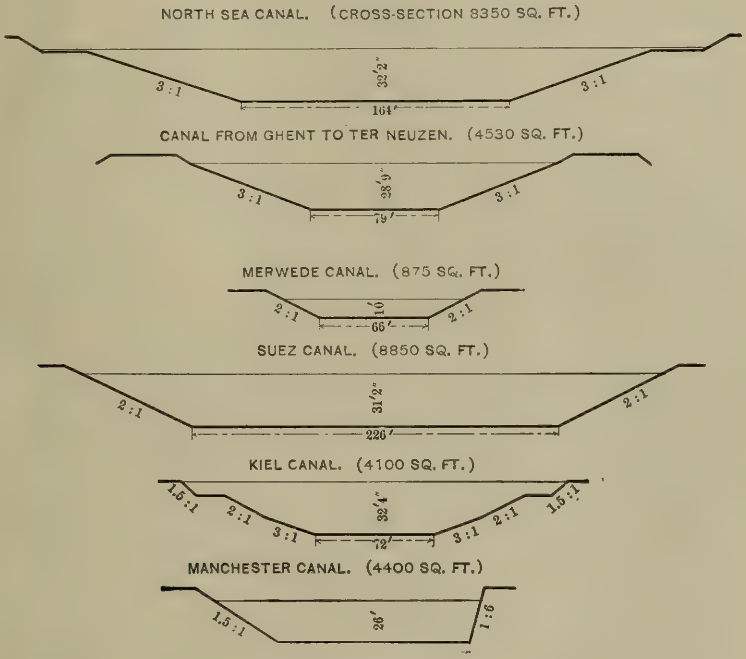

NORTH SEA CANAL. (CROSS-SECTION 8350 SQ. FT.)
CANAL FROM GHENT TO TER NEUZEN. (4530 SQ. FT.)
MERWEDE CANAL. (875 SQ. FT.)
SUEZ CANAL. (8850 SQ. FT.)
KIEL CANAL. (4100 SQ. FT.)
MANCHESTER CANAL. (4400 SQ. FT.)

FIG. 9.

The cost of the enlargement of the cross-section is estimated at $1 060 000, and the protection of the embankments at $180 000.

After the severe winter of 1890-91, a company, formed at Amsterdam to further the general interests of navigation, caused two ice-breakers to be built, the principal dimensions of which are given in Table 1. The cross-section of the ice-breakers is almost oval; the highest point of the screw is at least 4.10 ft. below the water-line. These ice-breakers shove upon the ice, which gives way under the weight of the vessel. In severe winters, Boat No. 1 will break the ice in the canal, while Boat No. 2 will be used in facilitating the approach to the docks, assisting entering ships.

TABLE 1.

	Ice-Breaker No. 1	Ice-Breaker No. 2.
Length, in feet	141.8	105.0
Beam, in feet	35.5	27.9
Depth of hold, in feet	17.4	12.8
Draft, while breaking ice, in feet	16.4	13.0
Engine	Triple expansion	Compound
Power indicated	830	350
Number of boilers	2	2
Heating surface of each boiler, in square feet	1 773	1 397
Steam pressure, in pounds	165	120
Cost	$76 560	$32 640

The North Sea Harbour.—The outer harbour is bounded by two piers, built of concrete blocks, placed on a layer of rough basalt. Below the low-tide mark the blocks are not cemented but are held together with iron clamps, fixed by means of oaken wedges.

Each pier is 5 014 ft. long. The land ends of these piers are 3 937 ft. apart; this distance gradually diminishes to 853 ft. at the sea end (about 4 600 ft. from the coast-line). The original width of this opening has been reduced to 656 ft. by large blocks of concrete of 11¼ and 19½ tons, which had to be placed afterward, to protect the sea ends of the piers from the severe blows of the waves.

By continual dredging, a channel, 820 ft. wide and originally 26¼ ft. deep below C. L., is maintained in the outer harbour. This depth, however, was increased in 1894 to 29½ ft. and in 1902 to 32⅝ ft. below C. L. The average yearly cost of dredging this channel is $88 000.

The North Sea Locks.—The North Sea Canal is separated from the North Sea by four locks, one of which serves exclusively as a water outlet.

PLATE X. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
VAN HOOGENHUYZE AND DE LINT ON
HOLLAND SHIP CANALS.

NORTH SEA CANAL.

THE CANAL FROM GHENT TO TER NEUZEN.

THE MERWEDE CANAL.

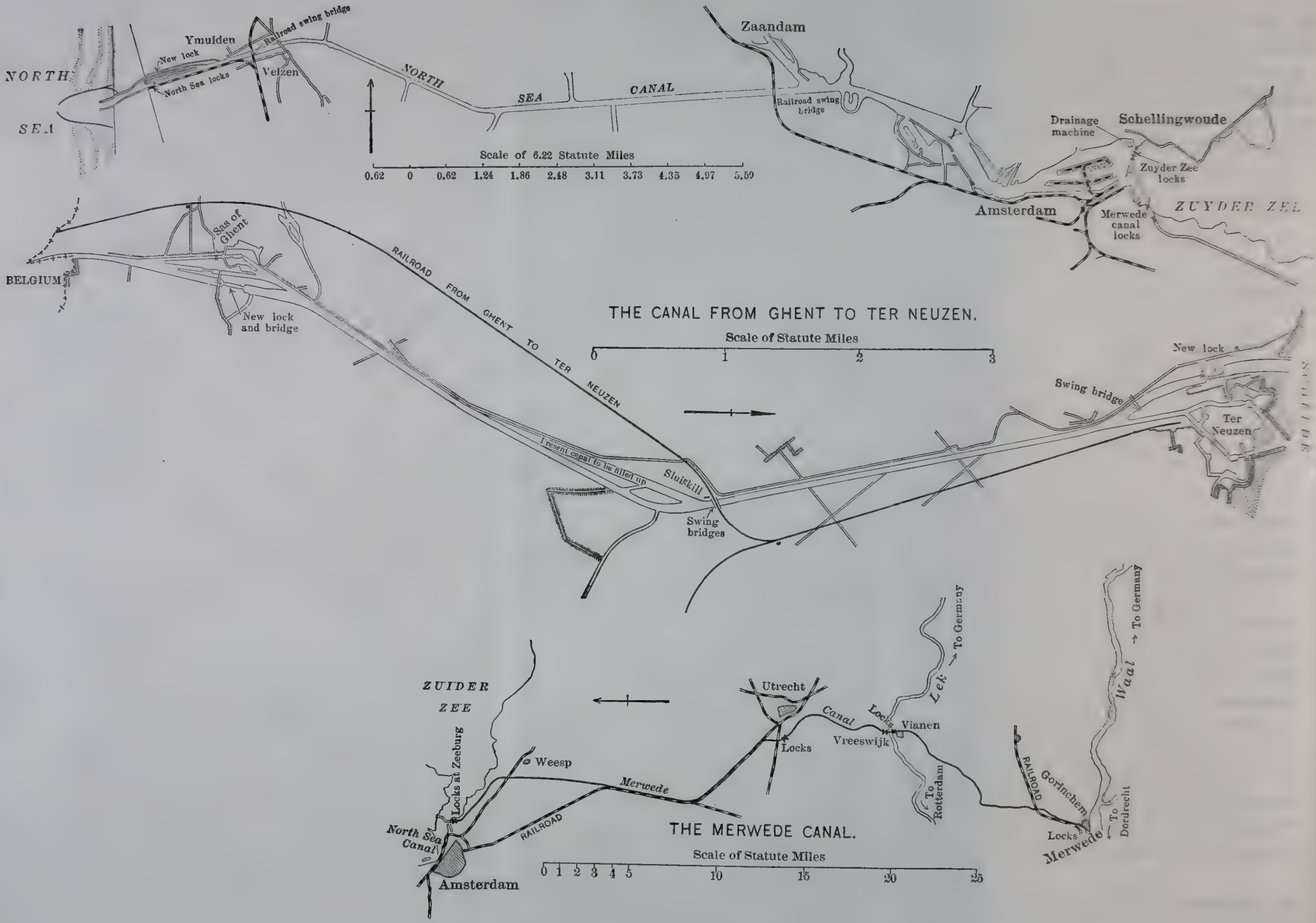
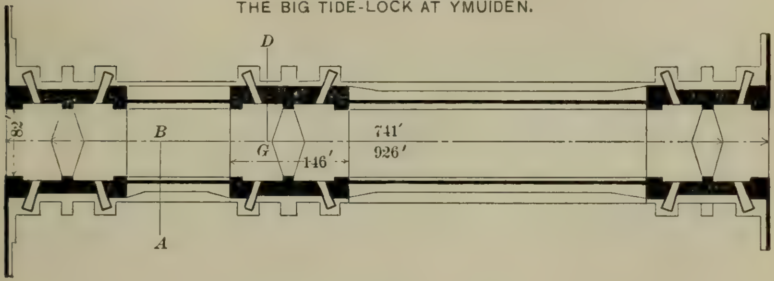


TABLE 2.—Quantities Dredged Since 1890.

Year.	Outside the harbour mouth.	In the harbour.	In the outer canal.	Average minimum depth below canal level.	Maximum draft of the ships passed through the North Sea Locks.
	Cubic Feet.	Cubic Feet.	Cubic Feet.	Feet.	Feet.
1890...........	2 926 000	13 029 000	660 000	26⅙	23⅔
1891...........	2 166 000	14 198 000	717 000	25⅔	23⅔
1892...........	3 104 000	26 539 000	1 381 000	26¼	23⅔
1893...........	2 153 000	19 810 000	859 000	26 7/12	23⅔
1894...........	5 048 000	17 073 000	1 437 000	26⅙	23⅔
1895...........	6 443 000	12 070 000	907 000	26 5/12	23⅔
1896...........	3 330 000	12 930 000	1 233 000	26½	23⅔
1897...........	3 667 000	19 602 000	1 328 000	26¾	26
1898...........	3 470 000	17 444 000	2 055 000	27¾	25¼
1899...........	3 688 000	13 668 000	1 942 000	28½	25¼
1900...........	3 747 000	16 995 000	1 617 000	29¼	25¼
1901...........	3 360 000	30 740 000	2 812 000	29¼	26
1902...........	4 939 000	34 384 000	2 606 000	29⅙	26¼
1903...........	6 892 000	25 271 000	1 980 000	30	26


THE NORTH SEA CANAL.

THE BIG TIDE-LOCK AT YMUIDEN.

Fig. 10.

The principal dimensions of the big tide-lock, containing three pairs of tide-gates and two pairs of ebb-gates, are: width 59 ft., depth on the miter-sill 24½ ft. below C. L., or 23⅓ ft. below low tide, length 394 ft. over all. The lock-chamber is divided into two sections by a pair of tide-gates. These sections are 230 and 146 ft. long.

To meet the increased demands of navigation, a second larger tide-lock was built between 1891 and 1895. Its dimensions are such that the largest ocean vessels built within the last years will be able to reach Amsterdam.

The principal dimensions are: Width, at a level of 8¼ ft. below C. L. and lower, 82 ft.; top of miter-sills 31⅔ ft. below C. L., or 30½ ft. below ordinary low tide; total length of lock-chamber 741 ft.

This lock-chamber is also divided into two sections, their lengths being 231 and 510 ft.

The soil on which the lock was built consists almost exclusively of sand or sand mixed with shells; only here and there at different depths vestiges of clay are found. The lock piers and the lock side walls are built on a concrete base 8¼ ft. thick, and made of brick, with limestone facings and granite copings. The lock walls have a front facing of rough basalt down to 8¼ ft. below C. L. The floor of the lock-chamber is paved with blocks of concrete so placed that at distances of 21 ft. continuous furrows remain, 6 ft. wide and perpendicular to the axis of the lock. These furrows (which were deepened to 38½ ft. below C. L.) and also the interstices between the blocks were filled with Portland cement, and the whole floor covered with brickwork, except where holes were left in the blocks. These were filled with gravel only, in order to allow the ground-water to rise and fall in them and so prevent the cracking of the floor.

To fill and empty the lock, there were constructed through the whole length of the side walls, tunnels 6½ ft. wide and in the axis 10½ ft. high, communicating with the lock-basin by 11 openings, 3 ft. wide and in the axis 4 ft. high.

The new lock has three pairs of tide-gates, the outer gates turning the water up to 18 ft. above C. L. and the intermediate gates and inner gates up to 13½ ft. above C. L. Moreover, there are three pairs of ebb-gates. All gates are constructed of mild steel with double plates. The length of each gate, along the center line, is 47½ ft., the greatest width is 4⅓ ft. The outer tide-gates are 50¼ ft. high, the other gates 45⅔ ft. Each gate is divided into watertight compartments, which serve as air-chambers and water-ballast chambers to prevent the gates from floating.

The cost of the new lock, including all minor works except the electric installation, amounted to $2 084 000.

The gates and the culvert sluices are opened and closed by electric motors. The gates can be opened or closed within 90 sec. against a head of 4 in., and the culvert sluices can be operated in 60 sec. against a head of 6½ ft. and a current of 13 ft. per sec. The electric motor operating a gate is a series-machine, designed for 360 revolutions.

YMUIDEN LOCK.

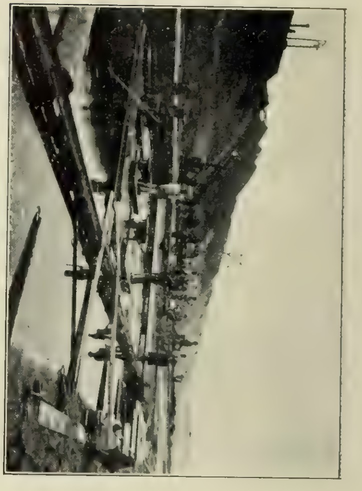


FIG. 1.—CONCRETE FOUNDATION OF THE SIDE WALL, SEPTEMBER 23D, 1891.

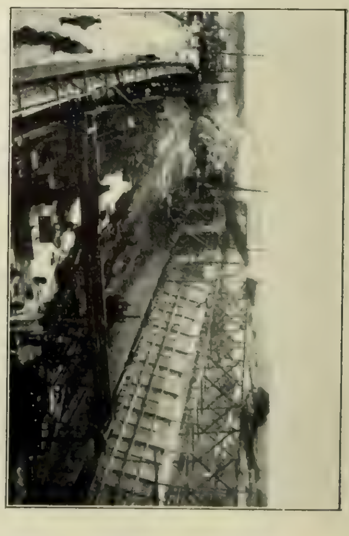


FIG. 2.—FLOOR OF THE LOCK CHAMBER, JUNE 15TH, 1893.

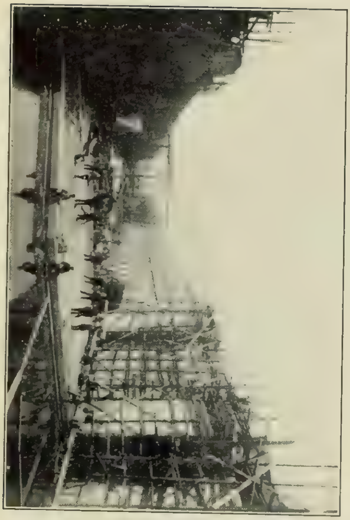


FIG. 3.—INNER LOCK PIERS, JUNE 21ST, 1894.

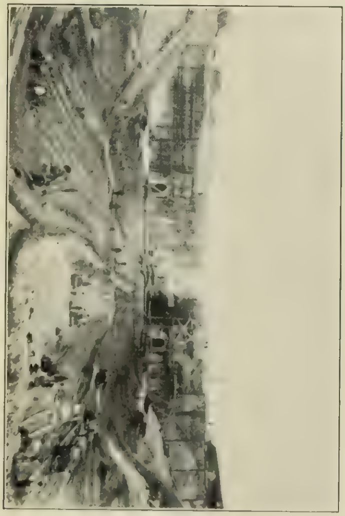


FIG. 4.—OUTER LOCK PIERS, JUNE 21ST, 1894.

The cost of the electric plant, including buildings, amounts to $220 000, and the running expenses are about $10 000 per year.

The service is continuous, day and night; at night the locks are lighted by electricity, supplied on the three-wire system. Twelve arc lamps of 10 amperes each are suspended on the piers from very strong poles capable of resisting the violent storms which sweep the flat country. Reflectors throw the light down upon the locks, leaving the surroundings in comparative darkness. Two of the lamp-posts bear colored bulbs, indicating whether the lock is free or not. Two other electric lights tell the approaching vessel which lock is to be used, the old or the new one. The way is shown by flash-lights, consisting of two groups of five incandescent lamps, fixed above the arc lamps at the entrance to the lock. A clockwork-driven switch in the power-house, with arc extinguishers, closes the circuit of these lamps for 2 sec. and then breaks it for 8 sec. There are altogether 500 incandescent lamps. The plant cost $19 000.

Outside the lock, a row of dolphins and mooring-posts has been erected. Each dolphin consists of 12 piles and cost $3 200.

At the entrances to the locks small estacades are built to guide the vessels and to protect the brickwork.

The Zuyder Zee Locks.—The Zuyder Zee is separated from the canal and "Y" by a dam. The principal dimensions of this dam are: height 13 ft. above C. L., width at top 10 or 13 ft.; the slope on the side of the Zuyder Zee is 3½ base to 1 rise, with a bench or berm 10 ft. wide, and the slope on the canal side, 2 base to 1 rise, with a berm 40 ft. wide.

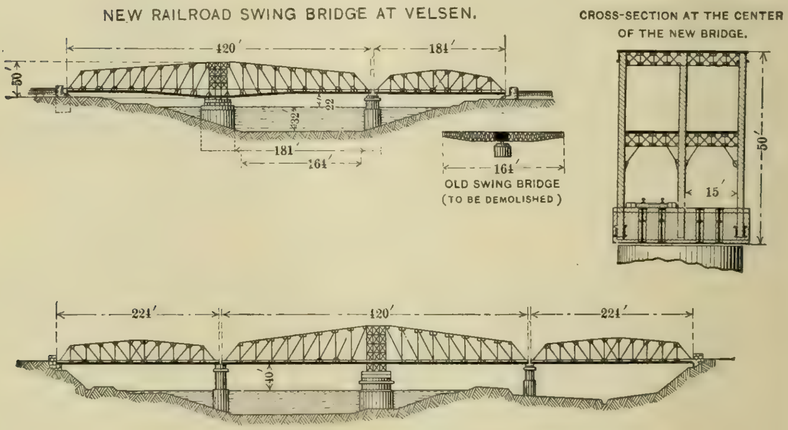
In this dam three locks and one outlet sluice were built. The widths of the locks are, respectively, 46, 60 and 46 ft., the depth is 13 ft. below C. L., and the lengths 239, 315 and 239 ft.

Bridges and Ferry.—Two railroad swing bridges and one swing bridge for ordinary traffic cross the canal. They leave a free opening of only about 63 ft., quite insufficient for modern traffic.

The road bridge will be replaced in a short time by a ferry, as it is too near the Velsen railroad bridge (distance 2 500 ft.) and also near a curve in the canal.

The new double-track railroad bridge at Velsen, which has been completed, but is not yet in operation, consists of a fixed span of 184 ft. and a swing bridge with two equal spans of 210 ft. each; the total weight of the swing bridge is 1 400 tons. The swing bridge rests in the center on a cast-steel ring, and 48 cast-steel conical rollers transmit the weight to the lower roller path. The ring has a diameter of 16¾ ft., the rollers of 1 ft.

The bridge (which carries a double track) consists of three main mild-steel girders 49½ ft. deep at the center, 16½ ft. apart from center to center. The distance between the water level and the bridge is 22⅓ ft. When the bridge is open it leaves a free passage of about 181 ft. The bridge is lowered or raised at the ends by movable wedges under the main girders.


NEW RAILROAD SWING BRIDGE AT VELSEN.

CROSS-SECTION AT THE CENTER OF THE NEW BRIDGE.

OLD SWING BRIDGE (TO BE DEMOLISHED)

NEW RAILROAD SWING-BRIDGE NEAR ZAANDAM.

FIG. 11.

As the unequal exposure to the sun sometimes causes a warping of the swinging parts, which would prevent the rails at both ends of the swing bridge from joining the rail ends of the fixed tracks at the same time, these have been made movable so as to make an adjustment possible. The bridge will be moved by an electric motor of 30 h. p.; it will be opened or closed, the locking of the ends included, in 90 sec.

The cost of the bridge, including substructure, etc., was $294 000.

The substructure of the railroad bridge near Zaandam will be completed in September, 1905, and is contracted for at a cost of $227 000. The dimensions are the same as those of the Velsen swing bridge; except that the difference between the water level and the bridge has been increased to 40 ft. to facilitate the navigation of smaller ocean vessels.

The Regulations of the Canal.—The regulations allow a maximum draft of 27 ft. at a level of 8 in. above C. L. and higher, 26½ ft. at a level of 4 in. above C. L., 26¼ ft. at C. L., and 11½ ft. between Amsterdam and the Zuyder Zee.

The maximum length is 575 ft. for lockage through the North Sea Locks and 295 ft. for the Zuyder Zee Locks. The harbour-master may permit the sluicing of vessels of greater length, circumstances permitting.

TABLE 3.—STATISTICS OF TRAFFIC ON NORTH SEA CANAL.

Locality.	Year.	SEA-GOING VESSELS IN BOTH DIRECTIONS.		RIVER CRAFT.	FISHING BOATS AND OTHER VESSELS IN BOTH DIRECTIONS.	
		Number.	Tonnage (in registered tons).	Number.	Number.	Tonnage (in registered tons).
North Sea Locks....	1890	3 685	3 279 000	....	4 067	50 000
	1891	3 814	3 552 000	....	4 335	58 000
	1892	3 688	3 639 000	....	4 355	62 000
	1893	3 675	3 540 000	....	5 168	71 000
	1894	3 960	3 865 000	....	5 633	87 000
	1895	4 429	4 015 000	....	6 495	97 000
	1896	4 352	4 381 000	....	6 439	104 000
	1897	4 723	4 896 000	....	4 739	64 000
	1898	4 537	4 733 000	....	5 777	91 000
	1899	5 157	5 448 000	....	4 831	86 000
	1900	5 223	5 560 000	....	4 647	93 000
	1901	4 447	5 552 000	....	5 267	139 000
	1902	4 246	5 727 000	....	12 320	386 000
	1903	4 017	5 666 000	....	10 139	261 000
Zuyder Zee Locks...	1890	20	1 615	79 766	....	....
	1891	14	2 314	106 818	....	....
	1892	17	1 122	94 063	....	....
	1893	14	1 674	88 991	....	....
	1894	13	1 465	88 013	....	....
	1895	18	2 639	71 698	....	....
	1896	14	1 855	74 468	....	....
	1897	13	1 175	71 270	....	....
	1898	19	3 070	74 151	....	....
	1899	26	3 305	74 777	....	....
	1900	30	3 403	71 667	....	....
	1901	18	2 298	68 654	....	....
	1902	16	2 195	67 270	....	....
	1903	21	2 523	72 635	....	....

The maximum of speed is restricted to:

4.86 nautical miles per hour for steamers with a draft of 6½ ft. and more;

6.48 nautical miles per hour for steamers with a draft between 5 and 6½ ft;

8.10 nautical miles per hour for steamers with a draft of less than 5 ft.

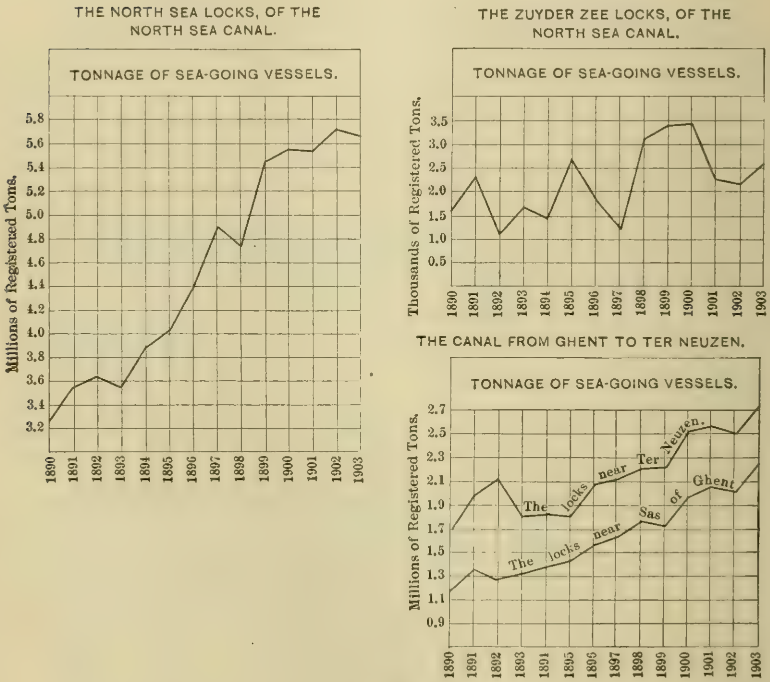


FIG. 12.

For towing, the maximum speed per hour is restricted to 4.86 nautical miles by day and 3.24 nautical miles by night.

All canal and harbour dues were abolished in 1890.

THE CANAL FROM GHENT TO TER NEUZEN (DUTCH SECTION).

This canal, which connects Ghent, the capital of East Flanders (Belgium), with the West Schelde was partly constructed in the sixteenth century, on a "patent" granted to the City of Ghent in

PLATE XII. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
VAN HOOGENHUYZE AND DE LINT ON
HOLLAND SHIP CANALS.

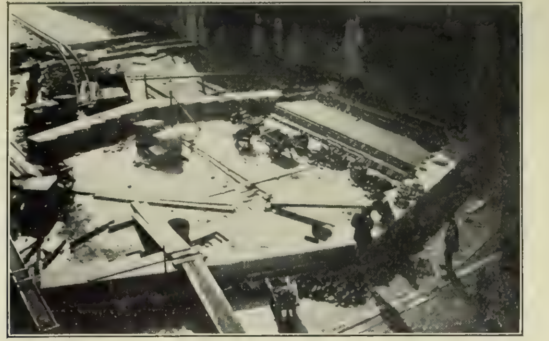


FIG. 1.—LOCK AT TER NEUZEN, MITER-SILLS BETWEEN THE OUTER LOCK PIERS, OCTOBER 9TH, 1903.

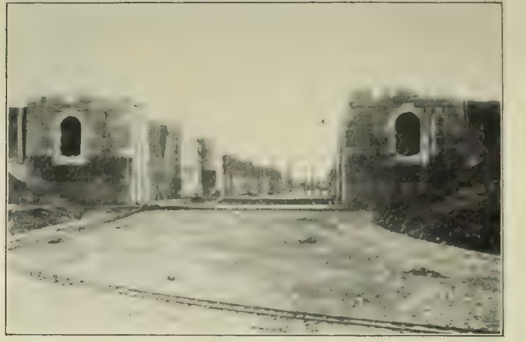


FIG. 2.—LOCK AT TER NEUZEN, OUTER LOCK PIERS. NOVEMBER 9TH, 1903.

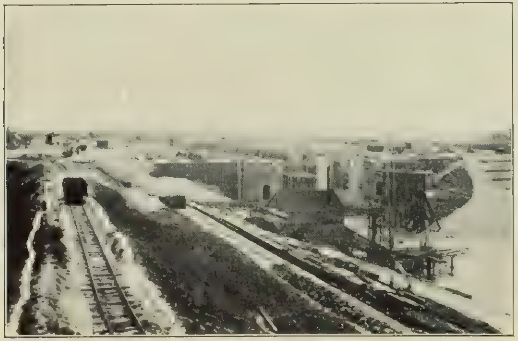


FIG. 3.—GENERAL VIEW OF THE LOCK AT TER NEUZEN. JUNE 15TH, 1904.

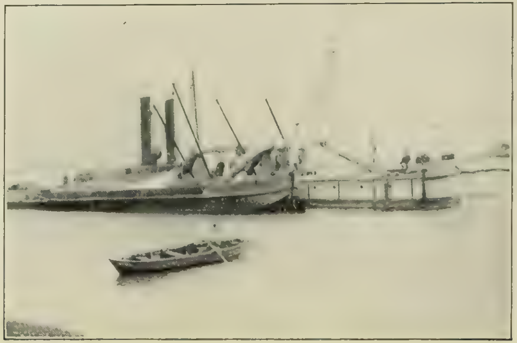


FIG. 4.—SUCTION DREDGE AT SLUISKIL

1547 by the Emperor Charles V. At that time, the canal ended at Sas of Ghent (Sas-Lock), communicating there with the Brakman (a branch of the Schelde) by a lock.

After the Peace of Munster, in 1648, the Republic of the United Netherlands controlled the navigation on the Schelde and closed the canal to Ghent.

As, in 1815, the Netherlands and Belgium were united by the Vienna Congress, the canal was again opened to navigation, but, as the Brakman had become very shallow, especially near Sas of Ghent, navigation was of little importance.

In 1823 it was resolved to extend the canal to Ter Neuzen, and in 1825-27 this work was carried out. This new section of the canal was separated from the older canal by the former sea-lock at Sas of Ghent.

The secession of the Southern Netherlands (Belgium) in 1830, was confirmed by the London Treaty of 1839, after which the canal was divided into a Belgian and a Dutch section. It is managed according to rules laid down in a convention between both countries on May 20th, 1843.

The depth of the outer miter-sill at Sas of Ghent was at that time only 14 ft.; at Ter Neuzen, however, the depth of the inner miter-sill was 18½ ft. In order to make the canal navigable for larger vessels a convention was held at Brussels on October 31st, 1879.

These improvements included an enlargement of the cross-section, and the building of a new lock at Sas of Ghent. The works were executed during 1882-85. The insufficient dimensions of the West Lock at Ter Neuzen, the sharp curve at Sluiskil, and many other points, however, required still further consideration.

Another convention was held in Brussels on June 29th, 1895, and, finally, the convention of March 8th, 1902, at The Hague, ordered the construction of a new lock with outer channel and junction canal, to the west of Ter Neuzen, the construction of a new lock to the east of Sas of Ghent, the improvement of the curve at Sluiskil, the enlargement and deepening of the cross-section, and the substitution of the bridges crossing the canal by others with a greater free opening.

The Canal.—The canal, connecting Ghent with the Schelde at

Ter Neuzen, has a total length of 19.84 statute miles, the Dutch section being 8.9 statute miles long. It consists of two sections, with dikes on both sides. The lower section, from Ter Neuzen to Sas of Ghent, has a length of 7.9 statute miles, a level of 8 in. below C. L., and is separated from the Schelde by two locks known as the West Lock and the East Lock. At Sas of Ghent both sections are connected by two locks, also known as the West Lock and the East Lock.

The upper section, from Sas of Ghent to Ghent, is connected at Ghent with the Schelde (where this river—contrary to the Schelde at Ter Neuzen—is of little importance), the Leye and many other canals for inland navigation.

Besides the traffic of sea-going vessels, an important traffic of Rhine barges and other river craft has developed. The canal does not serve as a drainage canal for the Dutch portion; for this purpose drainage canals have been constructed on each side, discharging their water through outlet sluices into the outer channel. At Ghent the canal is fed by the Schelde and the Leye; it also drains a part of the Belgian territory.

According to the treaty of November 5th, 1842, Belgium may discharge the water of the Schelde and the Leye into the canal. At present, this takes place through sluices in the lock-gates and the culverts in the lock-piers, and, if necessary, through the opened gates of the West and East Locks at Ter Neuzen. Accurate observations of this discharge, however, are lacking, as it is of rare occurrence. The maximum discharge is estimated at about 1 430 000 000 gal. in 24 hours; such a discharge, however, would cause considerable trouble. To remedy this, mild-steel ebb-gates of modified construction will be placed in the East Lock at Ter Neuzen, with sluices as large as possible. When the new gates are completed, the discharge through all culverts and through the sluices in the gates can amount to 2 000 000 000 gal. without causing too heavy a current in the enlarged cross-section, and without seriously altering the canal level.

The present canal has a depth of 20⅔ ft., a bottom width of 56 ft., and a width on canal level of 155 ft. After completion of the projected enlargement, which will be obtained by moving the eastern embankment backward, the depth will amount to 28¾ ft., the bottom width to 79 ft., and the width on canal level to 220 ft. The wet section will be at least 4 530 sq. ft. The curves of the canal will have radii of at least 3 300 ft., while in the curves the bottom will be enlarged according to the formula $4\,(R - \sqrt{R^2 - l^2})$, R being the radius of the curve in feet and l being 200.

After these improvements the entire canal will have one level, the level of the upper section being lowered 10 in., that of the lower one being raised 8 in.; the locks at Sas of Ghent only separating both sections in exceptional cases.

For the canal improvement at Sluiskil, three bucket dredges and one suction dredge are used at present. The dimensions of this suction dredge are as follows:

Steel hull, length	126 ft.
" " beam	24⅓ "
" " depth of hold	10½ "
Displacement	260 registered tons

Two engines, triple expansion, with surface condensers.
350 i. h. p. for the sand pump.
150 i. h. p. for the water pump.
Number of boilers, 2.

Heating surface of each boiler	966 sq. ft.
Steam pressure	165 lb.
Cost	$48 000

Forcing power, 20 ft. lifted over a distance of 3 000 ft., or 30 ft. lifted over a distance of 2 000 ft.
Diameter of the pressure pipes, 22 in.

This dredge is supplied with a screw, which can be connected with the shaft of the water pump. The vessel was built in the yards of L. Smit and Son, Kinderdijk, Holland.

A large part of the western bank protection has already been finished. This protection will be extended along the whole canal. It consists of a row of pine planks fitting into each other, 18 ft. long, 6 in. thick, with their top at C. L., held in place by a pitch-pine lath, 10 by 6 in. At distances of 10 ft. the revetment is anchored by means of iron anchors to an anchor pile with cross-pieces of pine wood. Behind the revetment, a layer of rubbish is laid, 24 in. wide and 12 in. thick. The cost amounts to about $5 per linear foot.

Probably this protection will allow a further deepening of the canal. It can be renewed without temporarily lowering the water level, and this is of great importance to navigation.

The canal is provided with a tow-path.

A plan for lighting the canal by electricity has been considered.

The Locks.—The old West Lock at Ter Neuzen has a length of 296 ft., a clear width between the lock-piers of 39½ ft., and a depth of 19⅔ ft. below C. L., at the top of the miter-sill. It is provided with one pair of tide-gates and one pair of ebb-gates in the inner lock-pier, and with one pair of storm-gates and one pair of "fan" gates* in the outer lock-pier.

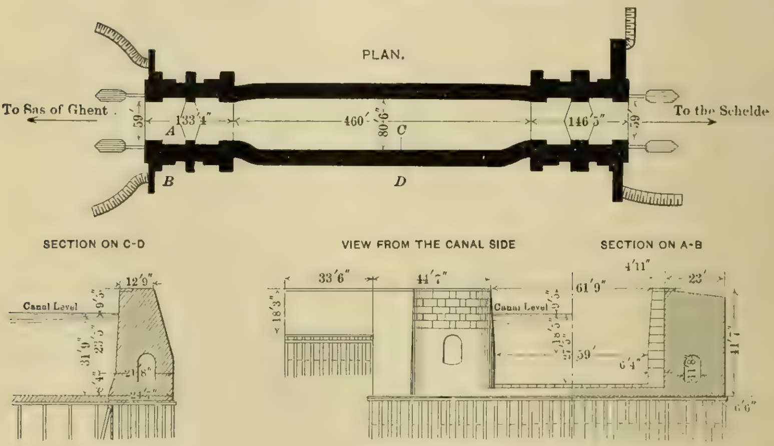

THE CANAL FROM GHENT TO TER NEUZEN.
THE NEW LOCK TO THE WEST OF TER NEUZEN.

FIG. 13.

The East Lock has a length of 378 ft., a clear width between the lock-piers of 26 ft., and a depth of 19½ ft. It is provided with one pair of storm-gates, two pairs of tide-gates and two pairs of ebb-gates.

The new lock to the west of Ter Neuzen, built according to the conventions already mentioned is nearly ready.

The length is 460 ft., the clear width between the lock-piers is

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* "Fan" gates, a Dutch invention, are gates of a peculiar construction, showing, in horizontal projection, the shape of a half-closed fan. They serve simultaneously as tide-gates, and as ebb-gates, and can be closed, without endangering the construction, against a current, or opened against a head of water

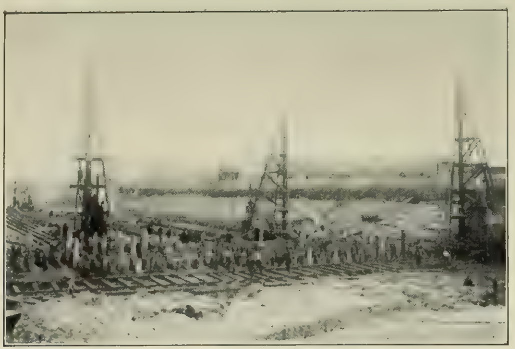

Fig. 1.—Foundation Piles. February 28th, 1902.

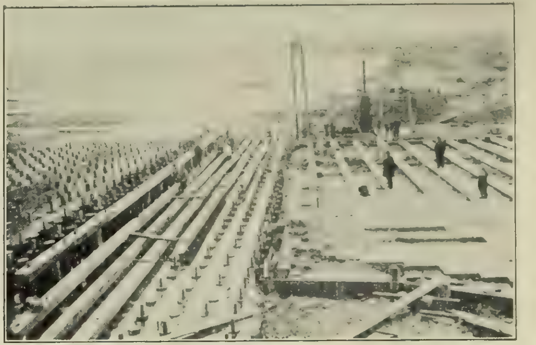

Fig. 2.—Foundation of Inner Lock Piers and Lock Chamber, May 24th, 1902.

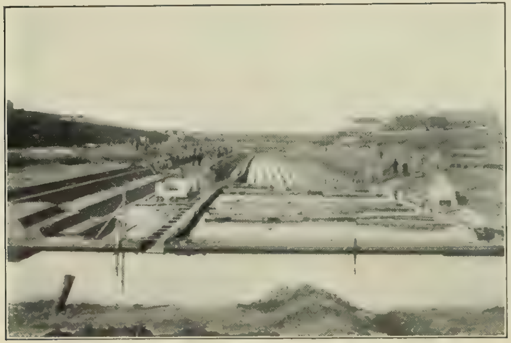

Fig. 3.—View of the Lock, October 31st, 1902.

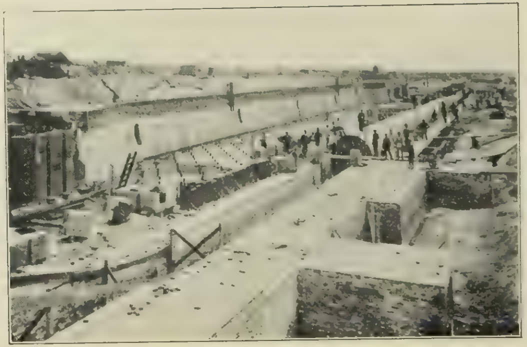

Fig. 4.—Side Walls and Culverts, July 2d, 1903.

Lock at Ter Neuzen.

59 ft., and the depth at the top of the inner miter-sill is 27½ ft. below C. L.

The foundation is of the usual Dutch type: a timber frame resting on piles. In order to protect the wood from the attacks of the so-called pile-worm it has been entirely covered by brickwork.

The lock-piers are constructed of brickwork, with copings of basalt, ashlar, and granite; the lower part of the side walls is made of brickwork, while the upper part is made of concrete; the copings are of basalt. Some locks in Zealand show that the facings of ashlar, especially in the deeper parts of the locks, are attacked to a certain extent by an animal called "drill sponge," which causes a crumbling to pieces, especially where the opening and closing of gates and sluices produce more or less heavy shocks. Therefore granite is employed for miter-sills and abutments of gates and sluice recesses.

On either side, running through the entire length of the side walls, culverts have been constructed, 11⅔ ft. high and 6½ ft. wide, communicating with the lock-basin by five openings, which can be closed by sluices. The culverts can be closed either by a culvert sluice or a swing gate.* It is intended to use the culvert sluice at the end of a lockage period and at other times to use the swing gates, as they require less time and work.

At the entrances of the lock small greenheart estacades are built to guide the vessels and to protect the brickwork.

The mild-steel gates are of the usual type, *viz.,* horizontal cross-pieces with heel-post and miter-post. They have a double plating, air-chambers and water-ballast chambers. The lock has two pairs of outer gates and two pairs of inner gates. The gates, culvert sluices and swing gates will be operated by electric motors. Each pair of gates is calculated for a maximum head of 18 ft.

The old or West Lock at Sas of Ghent, with two pairs of gates, has the following dimensions: length 305 ft., width 39½ ft., depth 14 ft. below C. L. The East Lock at Sas of Ghent, built during the years 1882-85, with three pairs of gates, has the following dimensions: length 384 ft., divided into two sections, 147⅔ and 236⅓ ft. long, 39½ ft. wide and 21½ ft. deep below C. L.

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* The swing gate or "toll-gate" (Dutch, "toldeur") is a construction much used in The Netherlands. It swings around a vertical axis, fixed almost, but not exactly, in the middle of the gate, one side being somewhat broader than the other, in order to facilitate the opening or closing by the difference in water pressure against both sides.

The new lock at Sas of Ghent, which is in course of construction, is projected with the same clear width as the new swing bridges which cross the canal; it will generally remain open.

The length of the lock is 656 ft., the width 86 ft., the depth, at the top of the miter-sills, 31⅓ ft. below C. L.

The Bridges.—The main canal will be crossed by four swing bridges. They leave a free opening of 86 ft.

As the estacades near the bridges and locks of the canal have to be very large, they will be constructed, not, as usual, of oak, but of West Indian and Australian wood, called greenheart, kawri or jarrah. The superiority of kawri over greenheart was demonstrated at Ostend; it is free from the usual defects, and shows no large clefts or cracks radiating from the center; besides, it is less difficult to get this timber in lengths of 60 ft.

THE CANAL FROM GHENT TO TER NEUZEN

THE NEW LOCK AND BRIDGE TO THE EAST OF SAS OF GHENT

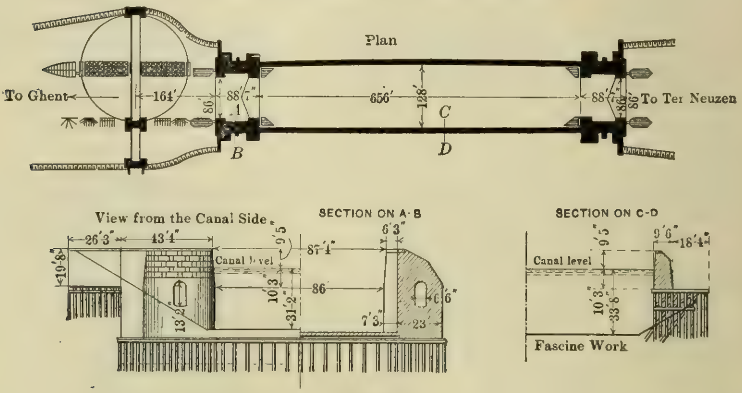

FIG. 14.

To compare the value of greenheart, kawri and jarrah to oak, the following experiments were made:

The resistance of samples of oak to bending was greater after being immersed for 14 days than in a dry condition; with kawri and greenheart the same results were obtained, while in jarrah it made no difference at all.

It appeared from these experiments that the resistance to bending varies in the following proportion:

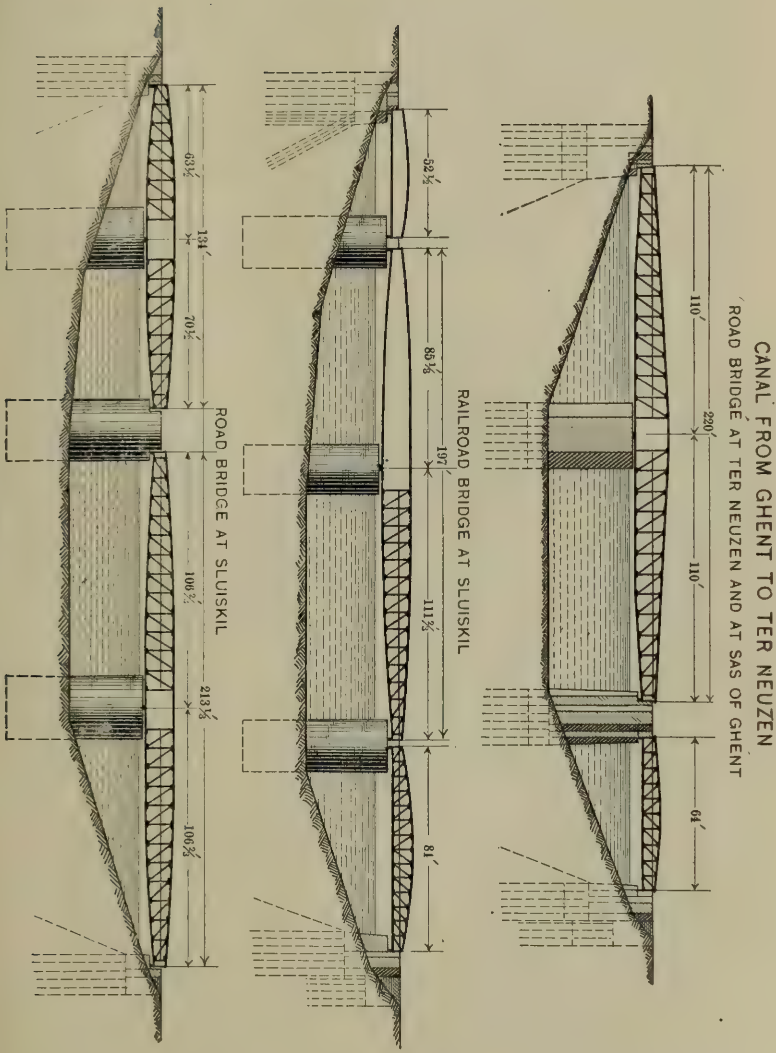
CANAL FROM GHENT TO TER NEUZEN
ROAD BRIDGE AT TER NEUZEN AND AT SAS OF GHENT
110'
220'
110'
64'
RAILROAD BRIDGE AT SLUISKIL
52½'
85⅛'
197'
111⅔'
81'
ROAD BRIDGE AT SLUISKIL
63½'
134'
70½'
106⅔'
213⅓'
106⅔'

Fig. 15.

Oak: greenheart: kawri: jarrah = 100: 185: 180: 143.

The deflection, at the moment of breaking, varied in the same species more than 100 per cent.

The greatest average deflection was observed in the samples of oak, and the average proportion was:

Oak: greenheart: kawri: jarrah = 100: 69: 86: 78.

The proportional resistance to compression was the following:

Oak: greenheart: kawri: jarrah = 100: 290: 200: 175.

It appears from these experiments, that oak is far inferior to the other kinds of wood.

The crushing experiments showed the following proportion of maximum of load:

Oak: greenheart: kawri: jarrah = 100: 340: 187: 170.

On storing the wood in dry places or in the open air, kawri, as well as jarrah, showed clefts, kawri, however, more than jarrah. It is therefore advisable to keep these kinds of wood under water.

Expenses.—The cost of the improvement of the canal from Ghent to Ter Neuzen (Dutch Section) is estimated to amount to $4 530 000.

Expropriation	$420 000
Earthworks	1 432 000
Bank protection	412 000
Lock at Ter Neuzen, including gates	731 200
Lock at Sas of Ghent, including gates	616 000
Swing bridge at Ter Neuzen	82 800
Road bridge at Sluiskil	113 600
Swing bridge at Sas of Ghent	82 800
Railroad bridge at Sluiskil, including changes made in the tracks	185 600
Various small works	118 000
Buildings	36 000
Electric plant	180 000
Supervision, etc.	120 000
Total	$4 530 000

The expenses are borne wholly by Belgium, which also reimburses the cost of maintenance.

The Regulations of the Canal.—The regulations allow a maximum draft of 19¼ ft. The maximum length is 296 ft., and the maximum beam is 37½ ft. for lockage through the West Lock at Ter Neuzen.

The maximum speed is restricted to:

4.70 nautical miles per hour for steamers of 9 ft. draft and over,

5.50 nautical miles per hour for steamers of less than 9 ft. draft,

THE CANAL FROM GHENT TO TER NEUZEN

PLAN OF THE BRIDGES AT SLUISKIL

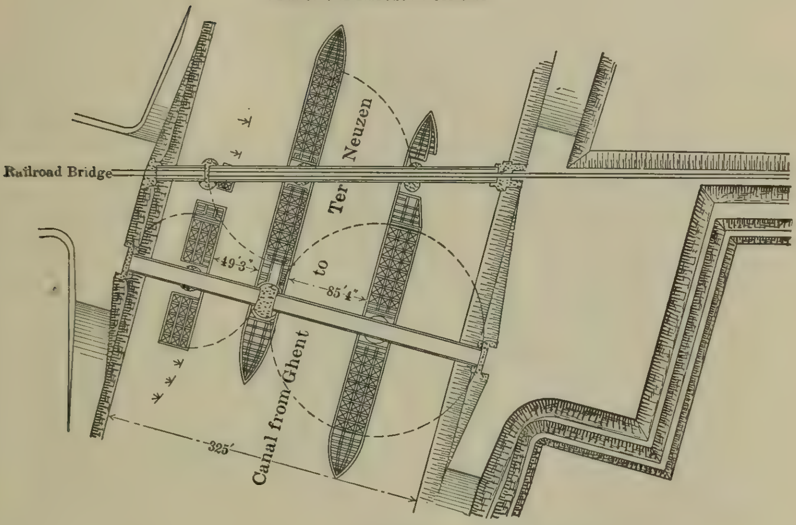

Fig. 16.

6.48 nautical miles per hour for steamers of less than 6½ ft. draft,

8.10 nautical miles per hour for steamers of less than 5 ft. draft.

THE CANAL FROM AMSTERDAM TO THE MERWEDE (MERWEDE CANAL).

To improve the communication between Amsterdam and the Rhine, the Government decided in 1881 to construct a new canal from Amsterdam to Gorinchem *via* Utrecht, crossing the River

Lek near Vreeswijk, and ending at the Merwede River (the principal branch of the Rhine).

The bottom width of this canal is at least 66 ft., with a depth of at least 10 ft. below water level. The works were commenced in 1882 and completed in 1893 at a cost of $8 300 000. The running expenses amount to an average of $52 000 per year.

The Canal.—The canal is divided into four sections: two on the north and two on the south of the Lek. The first section extends from the locks near Amsterdam to the lock near Utrecht, has a length of 115 800 ft., and is generally on the same level as the North Sea Canal, the locks near Amsterdam being closed only under special circumstances. The ordinary level is 0.20 in. below N. A. P.*

TABLE 4.—STATISTICS OF TRAFFIC ON CANAL FROM GHENT TO TER NEUZEN.

LOCALITY.	Year.	SEA-GOING VESSELS IN BOTH DIRECTIONS.		RIVER CRAFT IN BOTH DIRECTIONS.	
		Number.	Registered tons.	Number.	Registered tons.
Locks at Ter Neuzen.	1890	2 640	1 671 000	9 065	268 000
	1891	2 930	1 981 000	8 477	245 000
	1892	2 946	2 103 000	7 896	235 000
	1893	2 700	1 912 000	7 810	234 000
	1894	3 561	1 929 000	8 359	246 000
	1895	2 388	1 800 000	7 776	260 000
	1896	2 647	2 058 000	9 568	277 000
	1897	2 653	2 153 000	7 536	257 000
	1898	2 678	2 219 000	8 094	308 000
	1899	2 736	2 225 000	8 962	351 000
	1900	3 231	2 528 000	9 964	426 000
	1901	3 092	2 574 000	9 756	452 000
	1902	3 040	2 504 000	10 314	581 000
	1903	3 149	2 743 000	11 116	688 000
Locks at Sas of Ghent	1890	1 953	1 163 000	5 301	186 000
	1891	2 166	1 361 000	4 670	166 000
	1892	1 741	1 265 000	6 293	205 000
	1893	1 946	1 318 000	6 104	196 000
	1894	1 874	1 393 000	6 490	208 000
	1895	1 835	1 417 000	6 338	237 000
	1896	1 988	1 552 000	7 318	253 000
	1897	2 059	1 647 000	6 336	238 000
	1898	2 080	1 774 000	7 333	292 000
	1899	1 979	1 735 000	7 685	331 000
	1900	2 371	1 974 000	8 101	372 000
	1901	2 362	2 073 000	6 820	376 000
	1902	2 309	2 018 000	7 101	440 000
	1903	2 368	2 238 000	8 240	504 000

The second section extends from the lock near Utrecht to the lock near Vreeswijk and has a length of 32 900 ft. In summer the

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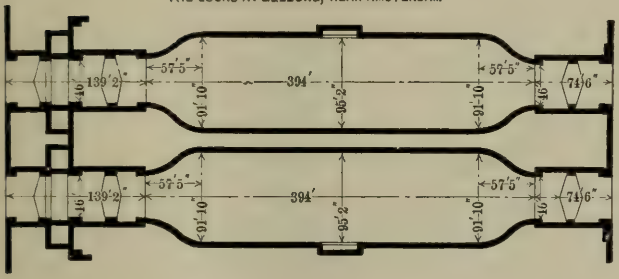
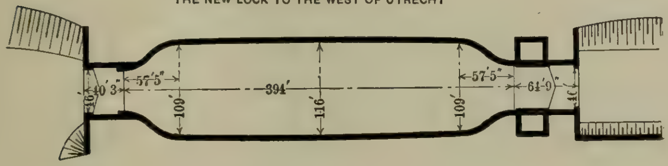
* N. A. P. = Mean water level at Amsterdam.

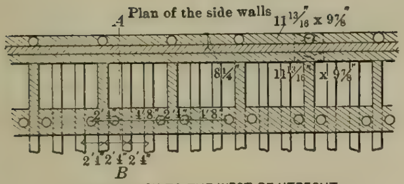
THE MERWEDE CANAL.

THE LOCKS AT ZEEBURG, NEAR AMSTERDAM



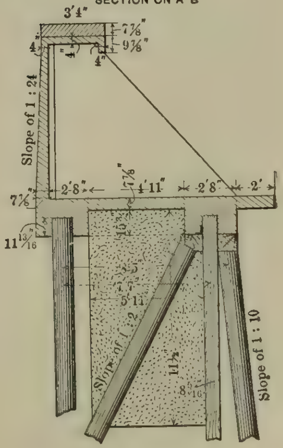
THE NEW LOCK TO THE WEST OF UTRECHT





THE NEW LOCK TO THE WEST OF UTRECHT

SECTION ON A-B



Draw-irons

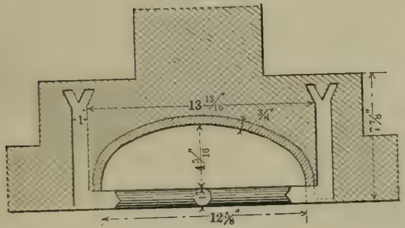


FIG. 17.

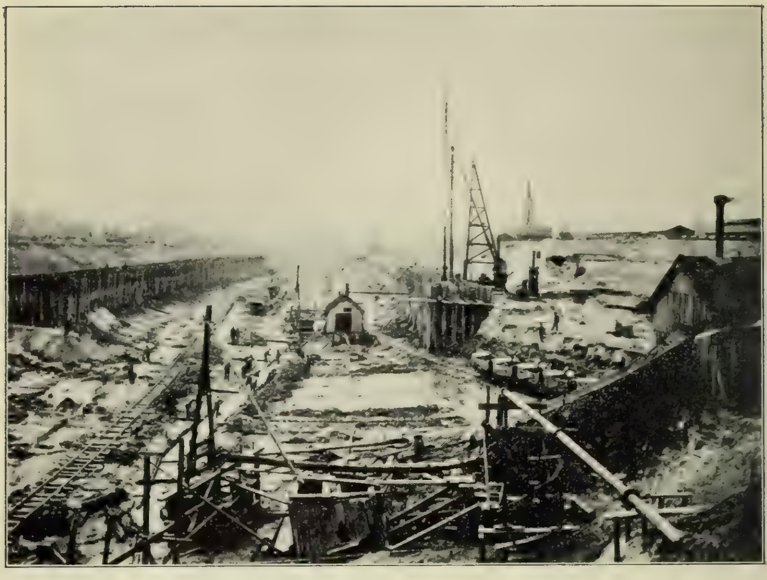


Fig. 1.—Lock at Sas of Ghent. Excavation for the Foundation, June 24th, 1903.

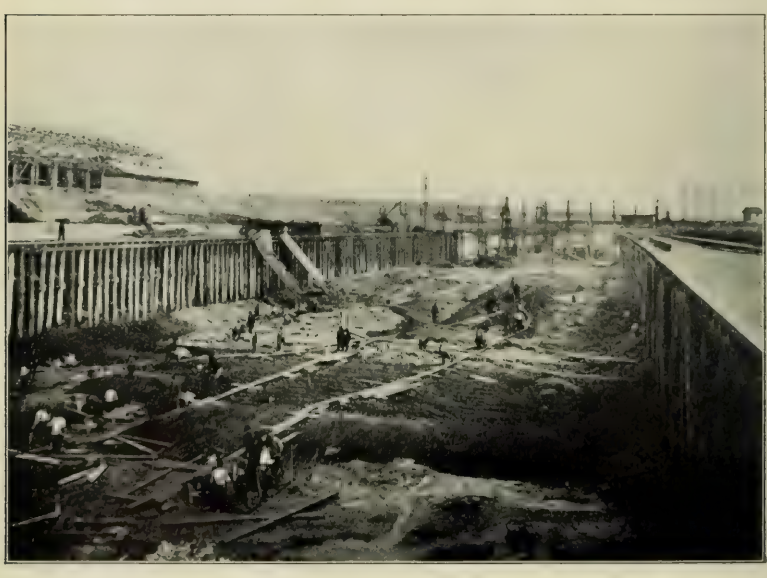


Fig. 2.—Lock at Sas of Ghent. Floor of the Lock Chamber, March 26th, 1904.

sions: length 263 ft., beam 33 ft., draft 8 ft., to be sluiced together with their tugboats.

The constantly increasing traffic made it necessary to construct a second lock adjoining the existing one at Utrecht. This lock will have a width of 116 ft.

While the walls of the existing locks are of masonry or basalt, the side walls of the new lock to the west of Utrecht, will be of concrete steel on a foundation of piles. They are constructed as follows:

The walls consist of a front wall or screen, 7⅞ in. thick at the base and 4 in. at the top, reaching from 1⅓ ft. below N. A. P. to 7 ft. above this level. At the base, this is connected with a platform, 7⅞ in. thick, resting on two stringers, 2⅔ ft. wide and 15¾ in. thick below the platform, 7 ft. apart from center to center, joined by cross-pieces of the same height and 1 ft. wide.

Every 7 ft. the front wall is connected with the platform by counterforts 6 in. thick. The top is enlarged, in order to carry granite copings 7⅞ in. thick.

The fore stringer of concrete steel is supported by pine piles at distances of 2⅓ ft. and 4⅔ ft. alternately, with tops penetrating 11 13/16 in. into the concrete. The back stringer of concrete steel rests on two wooden stringers with an interjacent wooden coffer-dam 8¼ in. thick, and supported on one side by pine piles 7 ft. apart, and on the other side by a row of slanting piles 2⅓ ft. apart, with a slope of 1:2.

According to a rough estimate $36 000 will be saved by adopting the concrete-steel construction. First it was planned to have the concrete wall rest on concrete-steel piles and a water-tight sheeting of concrete steel. This idea had to be abandoned, as the expenses ran too high.

The new lock will cost $244 000, not including the price of the ground. The houses of sluice-keepers and the bascule bridge will cost $45 000.

The gates of the existing locks are made of oak, those of the new lock will be made of djati (an East Indian tree).

Regulations of the Canal.—The police regulations for the Merwede Canal allow vessels of the following dimensions to pass through the canal:

Length of vessel 279 ft. and less, beam 34½ ft., draft 8½ ft.,
Length of vessel 279 to 296 ft., beam 34½ ft., draft 8 ft.,
Length of vessel more than 296 ft., beam 34½ ft., draft 7¼ ft.,
Vessels longer than 328 ft. are not allowed to enter the canal.

The maximum speed per hour is limited to:

4.05 nautical miles for vessels of 8¼ ft. draft,
4.86 nautical miles for vessels of 6½ to 8¼ ft. draft,
5.67 nautical miles for vessels of 4¼ to 6½ ft. draft,
6.48 nautical miles for vessels of less than 4¼ ft. draft.

Statistics of Traffic on Merwede Canal.—The traffic between Amsterdam and the Lek increases regularly, and was as follows:

In 1901, 56 345 vessels and a registered tonnage of 1 926 000,
In 1902, 60 475 vessels and a registered tonnage of 2 084 000,
In 1903, 62 096 vessels and a registered tonnage of 2 203 000.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

Paper No. 86.

ARTIFICIAL WATERWAYS.

INLAND NAVIGATION IN FRANCE.

By A. Charguéraud.*

Translated from the French by
Foster Crowell, M. Am. Soc. C. E.

The decennial period just passed is marked by a relaxing of energy in inland navigation works due to the almost complete fulfillment of the chief part of the general programme of 1879, known as the Freycinet plant. It ends by the adoption of a new programme, the execution of which will require about ten years more.

During this period local improvements have been made both in the management and the development of waterways.

The programme of 1879 included the construction of some new routes; certain of them have not been carried out, two being still in course of construction, these being, respectively, the canal to connect the Marne with the Saône and the canal from Montbéliard to the Upper Saône. But the most important part of the programme was the improvement and transformation of a number of waterways so as to constitute, in connection with the principal lines, a homogeneous system, navigable for a uniform type of boat, that of the Flemish barge, 38.5 m. (126 ft.) long, 5 m. (16 ft.) wide and 1.8 m. (6 ft.) draft, with a capacity of 300 tons.

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* Ingénieur en Chef des Ponts et Chaussées, Ingénieur en Chef de la Navigation de la Marne, France.

The expenditures from 1880 to 1892, inclusive, that is for 13 years, were about 500 000 000 francs; from 1893 to 1903, inclusive,—11 years,—the expenditures amounted to nearly 150 000 000 francs, after deducting expenses appertaining to the investigation of works not carried out and not including works of maritime canals or rivers.

The extent of the inland system of waterways has increased very slightly during this quarter of a century; only 600 km. (373 miles) have been built out of the present total of 11 600 km. (7 200 miles); the efforts have been concentrated on the transformation of the ways the diversity of which constituted an obstacle to long-distance transportation.

Table 5 gives the total lengths of waterways accessible to the Flemish barge type (the dimensions of which have been given) in 1878 and 1902, respectively.

TABLE 5.—French Waterways: Lengths of Rivers and Canals.

Years.	Rivers and streams. Kilometers.	Canals. Kilometers.	Total. Kilometers.
1878	996	463	1 459
1902	2 106	2 633	4 739

A corresponding transformation of canal-boats has taken place, as the figures in Table 6 bear witness.

During the same period the tonnage increased greatly. From about 2 250 000 000 kilometric tons (not including lumber in rafts) in 1880, it increased to 3 026 692 085 kilometric tons in 1887, and to 4 453 965 484 kilometric tons in 1902, being a growth of 98% in 22 years and of 47% for the second period alone.

The number of canal-boats has diminished slightly, but their capacity having increased, the total distance tonnage has grown larger at a somewhat greater ratio than the capacity (47% against 41%). In 1887, one ton of capacity corresponded to 1 115 kilometric tons, while in 1902 the same capacity corresponded to 1 156 kilometric tons; the average haul of a ton of merchandise in 1887 was 133 km.; in 1902 it had risen to 144 km.

TABLE 6.

Year.	Description.	Boats.		Capacity.	
		Number.	Percentage.	Tonnage.	Percentage.
*1887...	Boats of 38.5 m. and more.......	933	6	342 933	12.6
	Other boats......................	14 797	94	2 370 914	87.4
		15 730	100	2 713 847	100
1902....	Boats of 38.5 m. and more.......	6 366	41	2 391 147	62
	Other boats......................	9 014	59	1 459 727	38
		15 380	100	3 850 944	100

* First year census was taken.

Such, broadly stated, are the results of the works undertaken in carrying out the programme of 1879; they have met entirely the hopes of the authors of that programme and serve as examples for future progress.

Two features of the programme, as has been said, are still in course of execution; they are the canal from Montbéliard to the Saône on which work has been, for the time being, suspended, and the canal from the Marne to the Saône, which constitutes a prolongation of the Upper Marne Canal, and on which, during the past ten years, seventeen locks have been completed; eight others are well advanced and seven additional ones will be required to finish the canal.

Among these locks, of those completely finished, eight have lifts of 5.125 m. (16.8 ft.), the others have lifts of from 3 to 3.5 m.

With the exception of five locks constructed from 1893 to 1897, all the new locks are of masonry laid with slag cement, which gives greater hardness to the mortar and renders it more impervious. The portion of canal constructed since 1892 includes one section of rapid fall, 41 m. in a distance of 3 km. (72 ft. per mile), which feature was discussed at an international congress in view of the possible establishment of elevators. Thirteen projects were presented, and the Committee of Judges gave the preference to a plan calling for two funicular elevators with a lift of 20.5 m. each, estimated to cost 2 666 000 francs, not including the canal proper. The Navigation Service, however, decided on eight locks with a lift of 5.125 m. (16.8 ft.) each, spaced about 400 m. (about 1 300 ft.) apart. They have cost altogether about 1 500 000 francs.

The adopted plan was thus more economical than the elevators, but it should be said that a very fine stone quarry was found, situated about 8 km. from the center of the layout, which furnished, at a bargain, nearly all the stone required for the locks. This solution answers well for a canal of moderate traffic; it is much more economical in construction as well as in maintenance.

As to the canal prism, no new methods of construction have been used since 1892, but the processes resorted to for making it water-tight have been carried out with more and more care until a very satisfactory result has been reached, even when the water is first turned into the canal. The water-tightness is almost perfect in the embankments and only a little less so in cuttings through permeable soil, as well as in rock-cuts in which many fissures occur, and which frequently extend over long distances. When water is first turned on, the only leaks of any importance occur at points where the canal passes from fill to cut, and even these are not sufficient to prevent the water from reaching its normal level in three or four days. These results have been obtained by the application of the following principles suggested by the progressive experience of canal-builders.

As a first step the canal is lined on the inside with revetments of puddled clay over all embankments and in all cuts where there is any likelihood of settlement sufficient to crack the concrete pavement. These puddle revetments are 1.5 m. (4.9 ft.) thick.

In rock-cuts water-tightness is secured by a layer of concrete 0.1 m. (4 in.) thick.

The clay used for puddling is carefully selected, as the excavation proceeds, from among the argillaceous sandy soils, containing from 30 to 60% of sand. This is done entirely independently of the other cuttings. When the canal borings do not disclose good puddling clay in sufficient quantity, borrow-pits are opened, the latter often being afterward refilled with waste material.

When the puddle linings are to be placed over very permeable ground it is necessary to interpose a pavement of lean mortar to cut off natural filtration. Without this precaution the lining may be water-tight for a year or two, but seepage at length takes place from the damp earth, escaping into the natural openings of the soil; the staunchness is little by little destroyed until, at the end of a few years, large leaks suddenly take place. In the canal bottom the isolating mortar pavement is sometimes replaced by round filter sacks, precisely like the sacks used in road construction; this device has proved entirely successful.

The concrete pavements are made of mortar composed of slag cement, well rammed. Usually they are at once washed over with two coats of neat Portland cement and then receive a double coat of hot pitch. Finally they are covered with a bed of clay to protect them from the blows of pike poles, etc.

Among the features of construction of earthen dams for reservoirs at the present time, the following may be mentioned:

The guard-walls are monoliths of cement concrete, well rammed in layers of from 0.10 to 0.15 m. (4 to 6 in.). By taking necessary precautions to secure proper union between layers made at different times, it is possible thus to obtain masses much more water-tight than rubble masonry of the same thickness would be. Bond between the layers is best secured by applying, with a broom, a coat of neat cement of the consistency of cream.

The up-stream slopes of the dams are protected by slab pavements of well-rammed concrete made with Portland cement. These slabs have expansion joints every two meters.

This kind of pavement has the following advantages over stone pavement: First, it can be made much thinner, generally 0.2 m. (8 in.), and thus realize an important economy; second, the work is much more quickly done; third, it is easier to keep up, the length of the joints being much less; fourth, and finally, the search for very large surfaces of stone not likely to be injured by freezing water is often difficult and costly; the rammed concrete makes this search unnecessary.

Puddling the clay is done with grooved rollers, which give a pressure at the first passes of 210 kg. for each decimeter of length of face (116 lb. per in. of tread). This increases as the puddling continues, for as the material becomes compacted the grooves sink less deeply, thus shortening the virtual length of the roller while its weight remains constant. At the termination of the rolling the pressure is about double per unit of face.

The puddling rollers used in dam construction are of three types: First, a steam automobile roller, of 1.6 m. (5 ft. 3 in.) tread with Dion-Bouton boilers, this type having been used formerly at the Gros-Bois Dam (Bourgogne Canal); second, automobile rollers with 12-h. p. petroleum motors, invented especially for the canal from the Marne to the Saône by Chief Engineer Galliot; third, a traction roller with tread of 2 m. (6 ft. 6 in.) drawn by cable, used at the Bourdon Dam (Loing Canal). Of all these machines the most valuable is certainly the petroleum roller. As it costs little (about 6 000 francs, or $1 200), the Canal Administration has been able to procure a sufficient number to do 2 000 cu. m. (2 600 cu. yd.) of puddling per day, whereas the record previously had not exceeded 600 cu. m.

The petroleum roller has besides the advantage of occupying a small space and going everywhere. It would be difficult and even impossible to puddle every spot without it; parts of difficult access, notably in contiguity to masonry, would be poorly compressed, leaving very dangerous points for leakage.

Wherever possible coarse, sharp sand is mixed with the clay. A small proportion of such sand improves the puddle very much, even when it is as low as 30 liters per cu. m. (3%). The mixing is done very easily and rapidly by the well-known agricultural machine known as the "Canadian plow" or "cultivator," an apparatus with teeth formed of flexible steel springs.

TABLE 7.

	Length (meters).	Height (meters).	Greatest width at base (meters).	Cube of puddle (cubic meters).	Capacity of reservoir (cubic meters).
Villegusien Dam....	1 254	11.12	43.75	300 000	8 340 000
Charmer Dam......	363	15.5	64.19	190 000	11 600 000

When the clay is too damp it is necessary to add a small quantity of powdered hydraulic lime, mixed regularly and rapidly with a horse-traction mixer. The office of the lime is only to absorb the moisture and thus render the rolling easier. It is not thought that it improves the puddle; however, it drives away insects which might destroy in part the effect of puddling on the slopes.

The principal dimensions of the dams are given in Table 7.

The French Government, by the law of December 22d, 1903, was authorized to proceed with a number of different works, which, as far as inland navigation is concerned, are as follows:

IMPROVEMENTS.

	Appropriation.	
Deûle Canal	2 470 000	francs
Lens Canal	1 200 000	"
Aire Canal	4 500 000	"
Orléans Canal	7 000 000	"
Garonne	3 000 000	"
Canals in South France	11 000 000	"
Total	29 170 000	"

NEW WORKS.

North Canal	60 000 000	francs
Extension of the Ourcq Canal	36 000 000	"
Canal from Combleux to Orléans	4 000 000	"
Loire	1 660 000	"
Canal from Cette to the Rhone	4 240 000	"
Canal from Marseilles to the Rhone	71 000 000	"
Total	176 900 000	"

The works of improvement are to be done entirely at the expense of the Public Treasury. The new works, on the contrary, must be paid for in part by the commercial industries, to the extent of at least half, either by money actually furnished by them or, more generally, from tolls to be collected on new waterways. Under these circumstances it may be estimated that at least ten years will be required for completion with the ordinary credits of the Public Works budget.

THE NORTH CANAL.

The North Canal, which was declared of public utility by the law of December 23d, 1903, is in reality an extension of the St. Quentin Canal. This latter forms the only waterway connecting the region of Paris with the North of France. Not only does this single line provide passage for a greater tonnage than all the other lines of French transportation, but it includes a summit level of 20.4 km. (12.67 miles) upon which are stretches only wide enough for one boat to pass, aggregating 10.51 km. (6.5 miles), and with two tunnels of 5.6 and 1.1 km. (3.48 and 0.68 miles), respectively.

The annual traffic of the St. Quentin Canal is about 5 000 000 tons, two-thirds of it being bituminous coal, the consumption of which is continually on the increase in France. The collieries of the Nord and of Pas-de-Calais meet this consumption in larger and larger proportions, thus assuring to the transportation interests a constantly increasing business. Table 8 indicates this progression.

TABLE 8.—COAL CONSUMPTION IN FRANCE.

Years.	Tons.	Proportional numbers.	Proportion from the Nord and Pas-de-Calais.
1850	7 225 000	1	14 per cent.
1860	14 270 000	2	15 " "
1870	22 100 000	3	19 " "
1880	28 846 000	4	29 " "
1890	36 633 000	5	39 " "
1900	48 800 000	6.7	42 " "

It is estimated that the total tonnage of the waterways connecting the north of France with the central and eastern parts will amount to 10 000 000 tons, if these ways are put into proper condition to handle the traffic.

The proposed works are to be built according to the dimensions which have been adopted for waterways of the first class with a draft of 2.5 m. (8.2 ft.). Half of the cost, the whole being estimated at 60 000 000 francs, will be provided from the general fund, and the other half will be obtained from tolls, ranging from

0.006 to 0.012 franc per kilometric ton (0.2 to 0.4 cent per ton-mile).

Among the various improvements carried out on the waterways during the past ten years, the following are among the more interesting:

1.—On the canal from the Aisne to the Marne funicular haulage, authorized March 28th, 1893, has been installed in the tunnel under Mont de Billy. This tunnel situated on the summit level of the canal is 2 300 m. (1.43 miles) long with a mean width of 6 m. (20 ft.), not including a berm of 1.5 m. Towing in this long, restricted passage having become very difficult with the increase of traffic, a system of mechanical traction was established which had been used experimentally on the canals of Saint Maur and Saint Maurice, near Paris.

A complete description of this system was given in the report of the Minister of Public Works at the Universal Exhibition of 1900. An endless cable running on pulleys is driven by a 40-h. p. engine; the tow-lines are hooked to the cable by special attachments.

The traffic in both directions is served by running the cable alternatively, three hours at a time in each direction; the rate charge is 0.02 franc (0.4 cent) per ton of cargo; the haulage is obligatory. The expenses of operation, maintenance and sinking-fund may be taken at 20 500 francs; the annual revenue being at least 28 500 francs.

2.—On the Briare Canal.—Law of March 31st, 1893: Supplementary Feeder. Law of December 29th, 1899: Creation of a reservoir in the Bourdon Valley.

Up to 1895 the water supply for the summit level of the Briare Canal was obtained, during the dry season, from thirteen ponds with a total capacity of 11 300 000 cu. m. (400 000 000 cu. ft.). But the rains not always being sufficient to fill the ponds, and their capacity being overtaxed by the increased traffic on the canal, a steam pump of 640 h. p. had been installed at Briare to take water from the Loire by a double conduit composed of cast-iron pipes 0.90 m. (36 in.) in diameter. The water is conveyed 14.5 km. (9 miles) of which 3.5 km. is through a pressure conduit and 11 km. in an open flume. The maximum possible delivery is 800 liters (28 cu. ft.) per sec. Later it was decided to establish on Bourdon Brook, in the valley of the Upper Loing, a reservoir with a capacity of 8 000 000 cu. m., which will permit of always keeping in reserve, from year to year, the necessary quantity of water.

3.—On the Nivernais Canal, in its feeder system, is the reservoir of Settons, which has a capacity of 23 000 000 cu. m., formed by a masonry dam, 267.15 m. (876.25 ft.) long and 19 m. (62.3 ft.) high, built of granite founded directly on rock of the same nature. This dam has never shown any sensible movement, but there is considerable seepage, indicating a gradual deterioration in the mortar. A project has been studied for adding a masonry mask to protect the present structure from the action of the water, and to improve the general conditions by lessening the leaking and holding up the level. The expense of this will be about 700 000 francs. The guard-wall is of ordinary masonry with the exception of a length of 6 m. where reinforced concrete was used by way of experiment.

On the summit level of this canal, over a length of about 4 km. (2.5 miles) including a tunnel of 1 238 m. (4 060 ft.), a system of mechanical towage has been installed consisting of a towing apparatus moved by a petroleum motor. The cost of the same was 46 000 francs, of which 31 000 were for the machine and 15 000 for the chain.

The rate charged for towage is 0.04 franc (0.8 cent) per ton of cargo with the additional sum of 0.5 franc (10 cents) or 1 franc (20 cents) for the boat according as its capacity is less or more than 100 tons. Empties are towed free. Petroleum motors, with two speeds of translation of 0.60 and 0.30 m., have proved to be well suited for canal traction.

4.—On the canal from Roanne to Digoin there existed, especially at certain points, locks which were very close together, separated by very short reaches, on which it was difficult to maintain the level. These short reaches have been eliminated and each group of two locks has been replaced by a single lock of great lift. These locks have lifts of 5.25, 6 and 7.19 m. (17.22, 19.68 and 23.58 ft.).*

5.—Water communication from the north to Paris.—Law of

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* M. Mazoyer. Chief Engineer, Canal Service, *Annales des Ponts et Chaussées*, 1900, 2 ^{me} Trimestre, p. 258.

November 29th, 1898: Doubling the Locks and Various Improvements.

The waterways which connect Paris with the north of France, by reason of their great importance, have been objects of considerable improvement. M. Dusuzeau, Chief Engineer of that service, has contributed a note, reproduced here (Fig. 18), setting forth what has been done in this direction.

DIAGRAM OF NAVIGATION LINES BETWEEN BELGIUM AND PARIS.

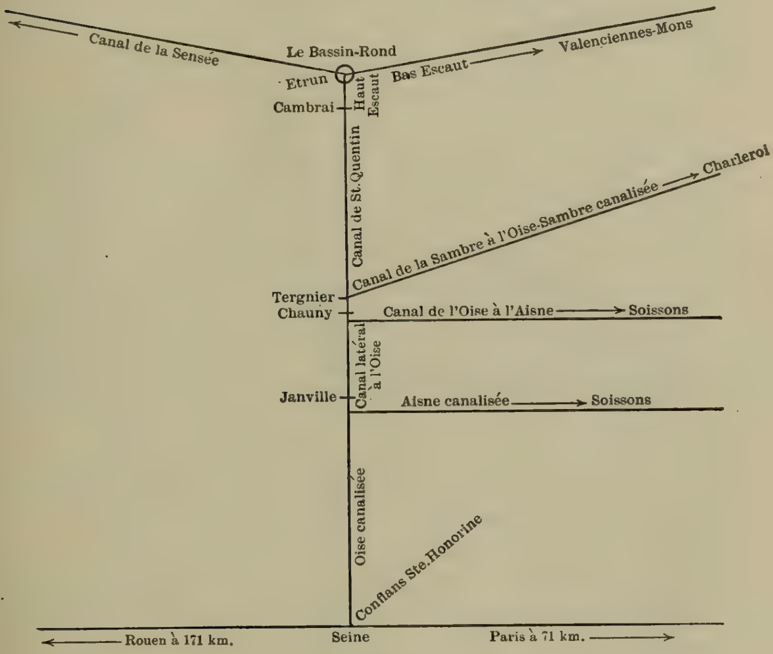

FIG. 18.

The system of navigation lines which unites Paris and the coal mines of the Departments of the Nord and Pas-de-Calais on the one hand and those of Belgium on the other, is, from the traffic point of view, the most important of French waterways. Besides the transportation of the fuel supply of Paris, it serves the very numerous factories which cover all Northern France (lace factories, looms, forges, furnaces, sugar-refineries, distilleries, stone-quarries, etc.).

The Sensée Canal serves the coal centers of the Douai Basin, and the Escaut, those of Valenciennes, uniting at Etrun (Round Basin).

The only artery extending to the Seine and Paris starts from there. This artery is composed of several trunk lines, as follows:

	Length in Kilometers.
Upper Escaut Canal, as far as Cambrai	12
St. Quentin Canal, Cambrai to Chauny	93
Lateral canal to the Oise, Chauny to Janville	34
Oise canalization, Janville to the Seine	104
Total length	243 (153 miles)

The three first-named trunks are composed of canals having identically the same cross-section; the draft is 2 m. (6.56 ft.), insured by a depth of 2.20 m. (7.2 ft.), and permitting the passage of boats loaded to a depth of 1.8 m. (5.9 ft.); the width at the bottom is 12 m. (39.6 ft.), barely sufficient for two boats of 5 m. (16.4 ft.) to pass each other; headway under bridges, 3.7 m. (12.14 ft.); dimensions of locks, 38.5 m. (126 ft.) available length by 5.2 m. (17 ft.) width. There are 44 locks with an average lift of 2.3 m. (7.54 ft.).

The boats of the canoe type which frequent the line, have a length of 38.5 m. (126 ft.) and an extreme width of 5 m. (16.4 ft.), which dimensions permit of a cargo of 300 tons when loaded to a submersion of 1.8 m. (5.9 ft.).

Towing on all these canals is done by horses organized in relays, although on the summit level of the St. Quentin Canal it is assured by steam towboats.

The River Oise, forming the last of the four trunks, has been canalized by means of 7 fixed diversion dams, of 1.5 m. (4.92 ft.) average fall, each of which is built in a lock placed in the bed of the stream, and presenting an available length of 50 m. (164 ft.), with a width of 8 m. (26.24 ft.) between cheek pieces. The width of the navigable channel of the Oise is everywhere greater than 20 m. (65.6 ft.).

Up to 1879 the average annual tonnage on the St. Quentin Canal had never exceeded 1 800 000 tons, corresponding, in round numbers, to the passage of 12 000 boats. At that period it was thought that this figure would never be surpassed and that it represented the maximum capacity of frequency of the canal, constituted as it was. However, the suppression of navigation duties, which became effective in 1880, and a considerable increase in the coal output from the collieries of the Nord and of Pas-de-Calais, developed a demand for the waterway which soon exceeded all expectations.

This line, only wide enough for two boats, and composed for the most part of canals with locks 38.5 m. long, suitable for 300-ton barges, has already had its capacity of frequency increased from 2 000 000 to 7 000 000 tons and it is foreseen that it will soon attain 10 000 000 tons.

The River Oise, between Janville and the Seine, that is to say for 104 km. (64.5 miles), consists of eight levels, the lowermost of which is maintained by the dam at Andresy on the Seine. The other seven are separated by masonry diversion dams with locks built into the latter. The locks, which are single chambered, have dimensions sufficient to receive boats of 500 tons (of the flat type) 45 m. (147.6 ft.) long, and 7.50 m. (24.6 ft.) beam. This kind of boat is disappearing gradually. The large locks built for them are found to be ill adapted, because of their excessive dimensions, to the trying conditions which occur when overtaxed by the frequent service of the 300-ton barges which circulate on the inland waterways of the north.

The system of canalization on the Oise has been modified since 1886. At each of the dams there has been introduced a derivation from 1 200 to 1 500 m. (3 936 to 4 920 ft.) long, containing a single lock 125 by 12 m. (410 by 39.36 ft.), calculated to lock six barges through at a time.

Towing by horses has here disappeared by common consent and without State intervention, and has been replaced by towboats which take five barges in tow at a time and are locked through with them.

The large locks are furnished with steel gates bordered with wood, the use of wood having been adhered to for facilitating the repairs of the damage very frequently caused by the boats striking the locks.

Wide-mouthed wickets in the gates permit very rapid filling and emptying. The wickets, like the gates, are operated with hand levers. The time consumed for one lockage, including the entering of the tow into the chamber, the emptying or filling and the passing out of the tow, is forty minutes. The locks, therefore, are capable of locking through $\frac{60 \times 5}{40} = 7.5$ barges per hour, not including the towboat, and the capacity of frequency for continuous operation would be $7.5 \times 24 = 180$ barges per day of 24 hours. Steam barges and barges moving separately are locked through the old locks so that the total lockages would represent 200 boats in 24 hours. This circulation, all of the outbound and one-third of the inbound boats being loaded, corresponds, deduction being made for days laid up, to a capacity of from 9 000 000 to 10 000 000 per annum.

To complete the transformation of the Oise canalization the fixed dams are to be replaced by movable dams, which will put an end to delays caused by freshets.

These delays are particularly objectionable on the Oise, which is the collector from the canals of the north; the latter are closed by ice nearly every year; a blockade then results all along the line until a thaw comes, and as floods generally follow thaws there are considerable interests which are endangered when navigation opens. The work of reconstructing the dams is in progress. They will probably be completed by 1906.

On the Escaut, the St. Quentin Canal and the lateral canal from the Oise measures for increasing the capacity have been in progress since 1880.

This line of navigation comprises on one part, 44 locks, 38.5 by 5.2 m. (126 by 17 ft.), and on another part, the St. Quentin summit level between the valleys of the Escaut and the Somme, covering a distance of 20 km. (12.4 miles) and containing two tunnels, 1 100 m. (3 608 ft.) and 5 670 m. (3.5 miles) in length, respectively.

The entire summit level was made for single track (so to speak), with bottom width of from 6.5 to 8 m. (21.3 to 26.2 ft.).

From 1880 to 1889 the existing works were improved without modification of their nature, but subsequently the frequency capacity of the locks and of the summit level was doubled.

For the locks it was only necessary to replace each old lock by a pair of twin locks. The new locks are modelled after the old ones, with identical entrances, gates, wickets and operating devices. Their depth has been increased from 2.2 to 2.5 m. (7.2 to 8.2 ft.), and their width from 5.2 to 6 m. (17 to 19.68 ft.). The advantage which results in rapidity and ease of entrance is considerable.

A pair of twin locks thus constituted will pass 12 boats per hour, and are sufficient to insure, for continuous operation, an annual circulation of 10 000 000 tons. In order to double the frequency capacity of the summit level recourse was had to a very simple solution.

The summit level had been operated by two steam towing-machines, moving back and forth and exchanging their trains at a central station. Two additional stations were established at the quarter points so that four sets of boats could be worked by the aid of four towing-machines.

This installation has already been in service several months, and from 120 to 130 boats per day can now be passed on the summit level as against 80 to 90 formerly. The doubling of capacity has not been realized because the speed of tows in the tunnel cannot be as great as in the open, so that the tunnel section for the present constitutes a weak element, but that will be remedied within a few months by removing the old banquette so as to enlarge the canal section, and when the present towing-machines of 40 h. p. are replaced by others of 75 h. p. The new towing apparatus will be actuated by electricity in order to overcome the inconvenience to the boatmen caused by the products of coal combustion in the tunnel. They will then be able to pass 150 boats through the tunnel in 24 hours, which will correspond to an annual traffic of at least 7 000 000 tons.

After the execution of the latter works, say toward the end of 1905, the frequency capacity of the line of navigation uniting Belgium with Paris, will be 7 000 000 tons over the St. Quentin summit and 10 000 000 tons over the rest of the route. This means that the average annual capacity would be 7 000 000 tons with continuous operation over the summit level and 16 to 17 hours' work per day, at the locks.

The capacity will attain, uniformly, 10 000 000 tons everywhere as soon as that of the summit-level tunnel can be doubled. It is probable that the remaining work will be executed with brief delay.

The cost of the improvements, including the doubling at the tunnel, will be less than 40 000 000 francs. For this moderate sum there will have been created, in effect, a new waterway, 243 km. (150 miles) long, carrying 8 000 000 tons annually. The investment amounts to 165 000 francs per km. ($53 130 per mile) and 0.02 franc per km. (0.644 cent per mile) and per ton annually transported. Few transportation lines have been established as economically.

TABLE 9.—MEAN TONNAGE ON THE ST. QUENTIN CANAL FROM 1879 TO 1903.

Year.	Mean tonnage.	Number of boats passing one lock.
1879	1 802 793	11 726
1880	2 041 669	13 886
1881	1 947 016	12 540
1882	1 912 460	12 894
1883	2 066 357	13 457
1884	2 226 506	14 387
1885	2 400 409	15 084
1886	2 700 223	17 099
1887	2 930 026	18 456
1888	3 028 215	18 697
1889	3 164 555	19 380
1890	3 102 729	17 772
1891	3 288 187	20 088
1892	3 474 251	20 813
1893	3 391 013	20 952
1894	3 870 731	23 469
1895	3 994 244	23 759
1896	4 364 640	25 350
1897	4 451 828	26 805
1898	4 636 034	27 450
1899	4 532 103	25 772
1900	4 606 048	26 354
1901	4 544 504	25 174
1902	4 355 520	26 347
1903	4 942 309	26 263

On the waterways in the Departments of the Nord and Pas-de-Calais, carrying out the laws of May 14th and 28th, 1900, the works will consist of the general improvement of the Sensée Canal and the establishment of receiving basins for boats at Aire and on the Deule River. The various improvements will cost about 3 000 000 francs.

The receiving basins will be large enough to contain 300 empty boats. The boats often have to wait a long time for their turn to be loaded at the coal dumps, causing blockades which will be avoided by the basins.

The works of improvement on the rivers, outside of their maritime portions, in the past ten years, have been few and purely local.

General Considerations.

In order to ascertain the progress accomplished in any given industry and what may still be expected therein, it is necessary to proceed by comparison.

In matters of transportation the railroad and the waterway are rivals, the coexistence of which assures the greatest sum of progress.

The isolated boatman, commanding his own craft, will long continue predominant in France as he is on the New York State canals. But, nevertheless, even with this system, important advances may be realized by studying and co-ordinating the various questions. This is the road which has been plainly entered upon in France, and, notwithstanding the difficulty of the problems presented, there is hope that advantageous solutions may be found.

So far as the construction of the waterway is concerned the great importance of increasing the cross-section so as to reduce the traction effort is recognized.

The depth of water, which generally has been 2 m. (6.5 ft.), has been increased to 2.5 m. (8.2 ft.) in the projects for new canals, and this improvement will be realized little by little upon the lines of large traffic.

In such conditions it may be admitted that the cost per kilometer of canal, which on the old system has always been less than that of railroads, will equal the latter. The dispositions of the structures required to overcome the differences of level always constitutes a delicate problem, as was well brought out in the discussions of the last International Congress of Navigation.

Numerous improvements of detail have been worked out both in new and in existing works.

The expenses of maintenance and administration, always lower on waterways than on railroads, do not appear to be susceptible of reduction.

Concerning the equipment much interest is shown in the increase of vehicular capacity; on railroads 50-ton cars are coming into use; in the North Canal project boats of 600 to 1 000 tons are advocated. From the point of view of the utilization of material, this increase of capacity of the vehicles does not appear to be of notable importance for the waterway.

There is an interesting contrast in Table 10 made up from the statistics of railroads and waterways.

TABLE 10.

	Years.	Number of vehicles.	Total capacity.	Mean capacity.	Tonnage, kilometric.	Kilometric tons per ton of capacity.
Railroads..........	1887....	234 171	2 224 625	9.5	9 882 095 749	4.442
"	1902....	279 554	2 907 362	10.4	16 097 052 016	5.536
Waterways........	1887....	15 780	2 713 847	172	3 026 692 085	1.115
"	1902....	15 380	3 850 944	250	4 453 965 484	1.156

From which may be deduced

	Increased percentage of mean vehicular capacity.	Increased percentage kilometric tonnage per ton of capacity.
Railroads...............	9.4	24.6
Waterways.............	45.3	3.6

Table 10 shows that on railroads very great progress has been made in the utilization of available capacity, while on the waterways, in this respect, things have remained nearly *in statu quo;* but the contrary is true in regard to the mean capacity of vehicles.

Taking the boat cost at 45 francs per ton of capacity, or 13 500 francs for a 300-ton barge, and the cost of railroad cars at 330 francs per ton, or 3 300 francs for a 10-ton car, the following results appear:

VEHICLE COST, PER KILOMETRIC TON.

Years.	Railroads.	Waterways.
1887.................	0.074 franc.	0.040 franc.
1902.................	0.060 "	0.039 "

The vehicle cost per traffic unit is thus seen to be much less for waterways than for railroads; but it should be noted here that great progress has been made on the latter, and that if the variations during the last 15 years continue proportionally, equality will be reached in about 25 years.

On the other hand, the figures of average haul have been raised as follows:

AVERAGE DISTANCE MOVED.

	Of one ton of merchandise.		Of one vehicle annually.	
Years.	Railroads.	Waterways.	Railroads.	Waterways.
1887 ..	134 km.	133 km.	11 619 km.	2 000 km. (estimated).
1902 ..	137 km.	144 km.	14 592 km.	

If these figures are combined with those which express the number of kilometric tons corresponding annually to one ton of capacity, it will be found that, in 1887, one ton of boat capacity transported in the entire year 8.38 tons, and in 1892, 8 tons. While on the railroads, one ton of car capacity transported in the two years, respectively, in 1887, 33.15 tons, and in 1902, 40 tons.

On the contrary, if the average speed of freight trains is assumed to be 30 km. (18.6 miles) per hour, which is probably too low, and that of boats to be 2 km. (1.24 miles) per hour, it follows that the average number of hours of movement per year is, for a car, 500, and for a boat 1 000 hours. Which shows that the time lost in repairs, freight-handling, delays, etc., on waterways is half as much as that on railroads.

A very notable improvement of the equipment of waterways, which may come to be realized, lies in proper modification of the bow and stern of the boats. The experimental researches made by M. de Mas in this direction, of which he has given an account at different congresses, have shown the favorable effect of raising the hull at the ends. Disposing them in spoon-shape may reduce the tractive effort required for a given speed to one-quarter.

It is desirable, therefore, that the rates for traction should be established in such a way as to grant reductions to the boats requiring less power. This would be the surest way to realize the desired improvement.

Power traction is being introduced on the waterways of Northern France. At the last Congress of Navigation a very complete memoir on this subject was presented. At that time the tendency was to develop the employment of electric traction by a trolley running on a track laid on the tow-path.

The tractive effort required for a canal-boat of the present type, loaded to a depth of 1.83 m. (6 ft.), to develop a speed of 0.75 m. (2.46 ft.) per sec., or 2.7 km. (1.7 miles) per hour, in a canal 10 m. (32.8 ft.) at bottom, 17.5 m. (57.4 ft.) at water surface and 2.5 m. (8.2 ft.) in depth, is 250 kg. (550 lb.), which could be reduced to 100 kg. (220 lb.) by refining the lines of the hull.

The work necessary to propel the boat 100 km. is thus:

$$\frac{75 \text{ m.} \times 250}{75} \times \frac{100}{2.7} = 92 \text{ h-p. hours.}$$

By slight modifications in the form of the boat this work might be reduced to 37 h-p. hours or even less.

A railroad train carrying 300 tons of paying load and weighing 400 tons, if run at a net speed of 30 km. (18.6 miles) per hour on a line with grades and curves equivalent in effect to a continuous grade of only 5 mm. per meter (½ of 1%), requires the expenditure of 2 000 kg. of tractive effort. The work required to send such a train 100 km. over such a line is 670 h-p. hours; in other words, from 7.3 to 18 times as much on the railroad as on the canal.

To sum up: the way, as much from the point of view of first cost as from the cost of maintenance, the equipment, both from the point of view of the capital required and of its utilization, and, finally, the matter of traction, all present marked advantages in relation to waterways over the corresponding elements of railroads. It is then in the direction of utilizing those elements that search must be made with the utmost care in order to realize progress in water communication; and it is in the commercial organization of transportation by water that efforts should be chiefly directed.

Questions of delays to freight, and of reform in rental charges are being studied seriously in the North, and there is good reason to hope that a satisfactory solution of the problem will be reached.

When concurrence shall be established between technical and commercial exploitation, inland navigation will be the object of great advancement. It is safe to say that, in France, a new era of progress in navigation is about to open. Engineers and manufacturers are combining to bring the antique mode of transportation up to the level of modern commercial methods.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 87.

ARTIFICIAL WATERWAYS.

ARTIFICIAL WATERWAYS IN THE UNITED STATES.

By William L. Sibert, M. Am. Soc. C. E.*

The people of the United States have not in the past, and probably will not in the future, fully appreciate the value of waterways, until they are confronted with the problem of placing their products in foreign markets at such a price as to compete successfully with foreign manufacturers. Then the cost of transporting the raw materials to the mills and the finished products to tidewater will often be determining factors as to ability to sell.

It is due, then, largely to the fact that the home demand of the United States has been about equal to the home supply that people in general have taken so little interest in waterways. It is thought that the construction of the Isthmian Canal will cause an awakening on the subject of water transportation in general, and will result in the construction of large systems of artificial waterways which will serve as feeders, directly or indirectly, to this great canal.

The anticipated use of the Isthmian Canal, from which the people expect returns commensurate with its cost, is as a short line for trade with the Far East, in which foreign competition must be met.

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* Major, Corps of Engineers, U. S. A.

The great steel manufacturers of the Pittsburg district are just now beginning to appreciate that it is water transportation on the Great Lakes, through the artificial channels in the connecting waters thereof made by the Government of the United States, that enables bringing together, partly at Pittsburg and partly on the shores of the Great Lakes, the iron ore of the Lake Superior region and the coal from Western Pennsylvania, at a cost such as to give this country a pre-eminent position in the steel world. The cost of mining the ore in the Lake Superior region, and of transporting it 850 miles by water, to Lake Erie ports, is about the same as the cost of transporting it the remaining 145 miles by railroad, from the Lake ports to the Pittsburg district, the water transportation cost being about $\frac{4}{10}$ mill per ton-mile.

Where artificial waterways are improved natural waterways, the Government of the United States pays for the improvement and for its operation, its return for first cost and maintenance being increased material development. Purely artificial waterways have been undertaken by the Government only in a few instances.

An examination into the cost of handling large quantities of heavy products on the improved Monongahela River and on the unimproved Ohio River, leads to the belief that the Ohio River may, when completely improved, be as effective a factor in transporting iron and steel from the Pittsburg district to tidewater as the Great Lakes are in bringing together the raw material needed in their manufacture. The systems of water transportation before mentioned are, therefore, essential factors in enabling the United States to compete successfully with foreign manufacturers of iron and steel.

The writer had occasion not long since to have a thorough examination made into the cost of transportation on the Monongahela and Ohio Rivers, and Table 11 gives the result of such investigation.

The hurry in American life has been so great that only those things are entered into which promise quick returns for the investment, and a great waterway project may be abandoned because a railroad can be built more quickly and cheaply, and because the additional cost of the finished product, due to lack of water transportation, still leaves a good profit, there being only domestic competition. Recollections of the experience with a number of very small canals in use in the United States fifty years ago are respon-

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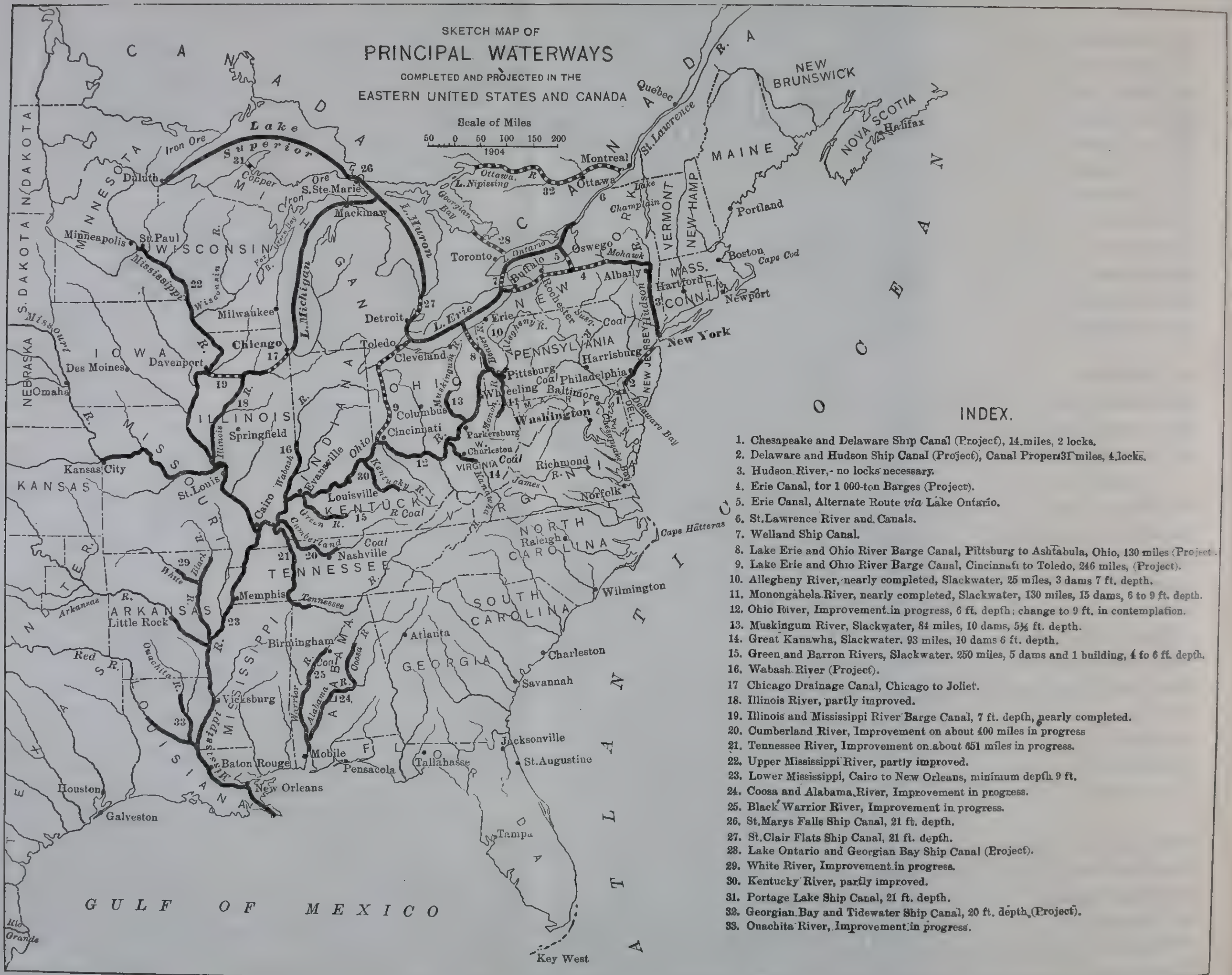

SKETCH MAP OF
PRINCIPAL WATERWAYS
COMPLETED AND PROJECTED IN THE
EASTERN UNITED STATES AND CANADA

INDEX.

1. Chesapeake and Delaware Ship Canal (Project), 14 miles, 2 locks.
2. Delaware and Hudson Ship Canal (Project), Canal Proper 31 miles, 4 locks.
3. Hudson River, - no locks necessary.
4. Erie Canal, for 1 000-ton Barges (Project).
5. Erie Canal, Alternate Route *via* Lake Ontario.
6. St. Lawrence River and Canals.
7. Welland Ship Canal.
8. Lake Erie and Ohio River Barge Canal, Pittsburg to Ashtabula, Ohio, 130 miles (Project
9. Lake Erie and Ohio River Barge Canal, Cincinnati to Toledo, 246 miles, (Project).
10. Allegheny River, nearly completed, Slackwater, 25 miles, 3 dams 7 ft. depth.
11. Monongahela River, nearly completed, Slackwater, 130 miles, 15 dams, 6 to 9 ft. depth.
12. Ohio River, Improvement in progress, 6 ft. depth; change to 9 ft. in contemplation.
13. Muskingum River, Slackwater, 84 miles, 10 dams, 5½ ft. depth.
14. Great Kanawha, Slackwater. 93 miles, 10 dams 6 ft. depth.
15. Green and Barron Rivers, Slackwater. 250 miles, 5 dams and 1 building, 4 to 6 ft. depth.
16. Wabash River (Project).
17 Chicago Drainage Canal, Chicago to Joliet.
18. Illinois River, partly improved.
19. Illinois and Mississippi River Barge Canal, 7 ft. depth, nearly completed.
20. Cumberland River, Improvement on about 400 miles in progress
21. Tennessee River, Improvement on about 651 miles in progress.
22. Upper Mississippi River, partly improved.
23. Lower Mississippi, Cairo to New Orleans, minimum depth 9 ft.
24. Coosa and Alabama River, Improvement in progress.
25. Black Warrior River, Improvement in progress.
26. St. Marys Falls Ship Canal, 21 ft. depth.
27. St. Clair Flats Ship Canal, 21 ft. depth.
28. Lake Ontario and Georgian Bay Ship Canal (Project).
29. White River, Improvement in progress.
30. Kentucky River, partly improved.
31. Portage Lake Ship Canal, 21 ft. depth.
32. Georgian Bay and Tidewater Ship Canal, 20 ft. depth (Project).
33. Ouachita River, Improvement in progress.

sible also for very erroneous impressions as to the capabilities of inland waterways generally.

TABLE 11.—Cost of Transportation.

On a basis of 2 000 000 tons on the Monongahela and 3 500 000 tons per annum on the Ohio, etc.

Towing in fleets of barges.	Miles.	Average tons in fleets.	Average cost per ton, in cents.	Cost per ton per mile, in cents.	Capital invested.	Annual operating expenses.	Remarks.
Monongahela River. †Coal mines to Pittsburg	52	2 500	9.4	0.18	$526 000	$83 946.50	Empty barges returned to mines.
Ohio River. Pittsburg to Louisville; river improved to a 6-ft. depth	600	8 500	37.6	0.063	2 424 000	1 026 510.00	Empty barges returned to Pittsburg.
Ohio River. Pittsburg to Louisville; river improved to a 9-ft. depth	600	12 500	24.1	0.04	2 080 000	845 000.00	"
Ohio River. †Pittsburg to Louisville; present freshet system	600	15 000 to 25 000	45.8	0.076	5 000 000	1 604 800.00	"
Ohio and Mississippi Rivers. Louisville to New Orleans; river improved to a 9-ft. depth	1 360	25 000	53.38	0.039	3 480 000	1 868 632.50	Empty barges returned to Louisville.
Pittsburg to New Orleans on improved 9-ft. depth	2 000	....	77.48	0.039	....	....	Empty barges returned to Pittsburg.
†Pittsburg to New Orleans; present freshet system	2 000	....	135.00	0.0675	....	....	*Not returning empty boats, but including their value in cost of transportation.

* The boats in use are of cheap construction.
† Actual practice.
The costs in Table 11 include 5% on the investment and 15% for annual depreciation of plant.

Canals.

The Commercial Aspect of Canals as Compared with Railways.

The great cost of modern canals restricts them to routes on which a heavy business is certainly to be relied upon. Engineering problems relating to the capacity of canals, number and arrangement of locks or lifts, and provisions for their water supply, govern the cost; but no cost should be esteemed too great in any particular case, provided sufficient commercial benefits will follow the improvement, since the cheap handling of the heavy raw products essential in manufacture is the main source of a nation's commercial greatness.

Commercial benefits, therefore, are the first consideration which should engage the attention of the promoters of any canal, and these benefits must be made very convincing if it is hoped to enlist capital in any costly undertaking, or to enlist sufficient public interest to cause the Government to undertake the construction of any canal.

No natural or artificial waterway, either in the United States or abroad, can, it is thought, be pointed to as having worked a material injury to the railway interests; nevertheless, it is sometimes argued that the capital invested in railways, which is truly a vast sum, may be depreciated by the construction of canals.

The unit of cargoes in any canal which is likely to be constructed in the United States will probably be not less than 1 000 tons per boat, hence canals are eminently well adapted for business of a bulky or heavy nature to and from points where such freight is offered constantly in great volume. Traffic in the requisite volume at the termini of canals, or at the large towns on their banks, can therefore be expected to be found at only a few points. Hence it cannot be claimed for canals that they will be able to displace the work of railroads in the transportation and distribution of the lighter, miscellaneous, or high-classed freight, upon the movement of which the railways make the greater portion of their profits.

It is true in the United States, as it was in France and Germany at one time, that the attempt of the railways to transport bulky freight of low intrinsic value resulted in "congestion" and injury to their general utility, tending to retard the development of new industrial establishments along their lines.

Railroads are forced to charge for each 100 miles of transit of fuel about as much as its original cost loaded on cars. Successful manufacture with such fuel cost is often impossible. If, however, fuel or iron ore, or both, can be transported in large quantities by water at about one-fourth the railroad cost, then more manufacturers can afford to operate, which, of course, means a greater business

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SIBERT ON
ARTIFICIAL WATERWAYS IN THE UNITED STATES.

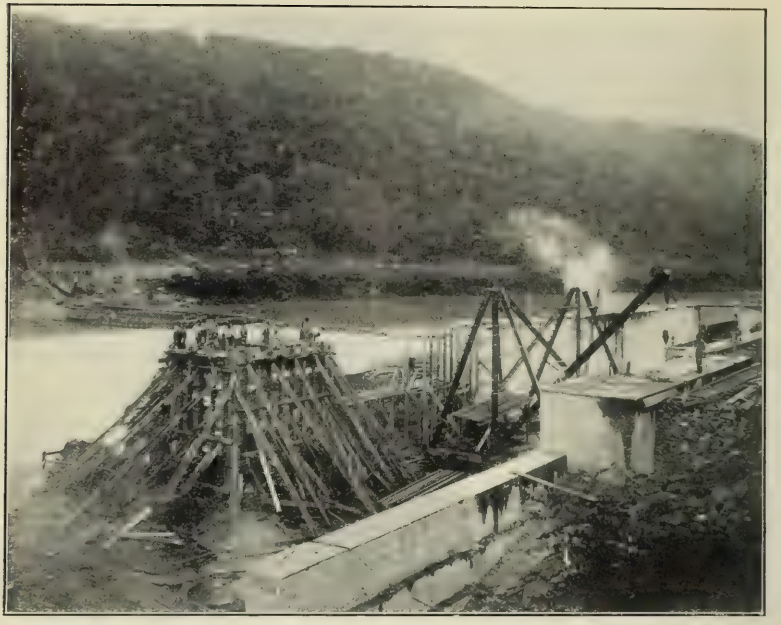

FIG. 1.—CONSTRUCTING MONOLITHS FOR LOCK WALLS.

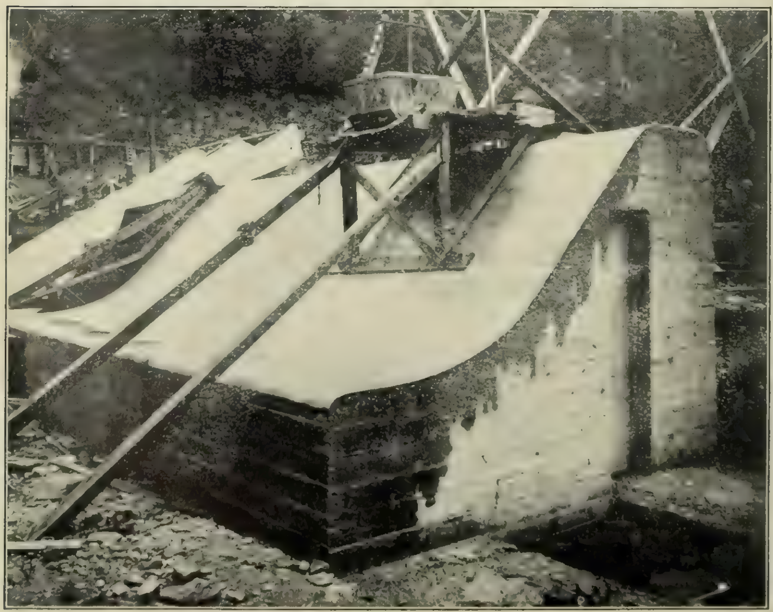

FIG. 2.—METHOD OF KEYING MONOLITHS.

for the railroad than would be possible without the water transportation.

Such are some of the considerations which have influenced the advocates of waterways in the United States and have led them to the conviction that not only manufacturers, miners, and shippers of all classes of goods may be benefited by the construction of canals, but that the railway companies may also participate in such benefits. They certainly have participated in the results following the improvements in the Great Lakes System, to which improvements must be credited largely the recent remarkable development in the manufacture of iron and steel in the United States.

Construction and Administration.

Nearly all of the small canals completed in the United States prior to 1850, about which time their construction ceased, were built and maintained by individual States, notably New York, Pennsylvania, Maryland and Virginia. In a few cases the canalization of rivers was also undertaken by the States. Gradually, however, by purchase or gift, the United States has come into possession of nearly all the old river improvements, and in some instances has greatly enlarged and extended them. So far, however, nothing has been done toward the resuscitation of the old State canals, which are too small for economical use in modern transportation.

The active assumption by the General Government of the care of the natural waterways has prevented, in many cases, their destruction as possible avenues of commerce by encroachments and obstructions of various kinds, so that they remain, or can be made available, with free rights of way for future conversion into artificial waterways—a consideration of great importance and value.

The General Government has done but little toward the construction of canals for the purpose of connecting different river systems, the Hennepin Canal being about the only case of any importance in this direction.

On the map of the Eastern United States, Plate XV, the principal waterways, rivers and canals, completed and projected are shown. Some of these projects have their outlets to tidewater from the Lakes through the State of New York, while the others reach the sea *via* the Mississippi River. The natural barriers to an effective inland water route connecting the Great Lakes and Mississippi River Systems are not great.

A glance at the map reveals the fact that a counterpart of the hydrophysical conditions of Russia exists in America. For the Volga, which extends its navigable arms toward St. Petersburg and actually makes the connection by a canal, there is, in the United States, the Mississippi and its branches extending to points where barge canals are practicable, *via* the Great Lakes to the Hudson near Albany. Along these inland troughs, or natural depressions in the topography of the two continents, are located the regions of the greatest agricultural production, and in addition, in America, there are the greatest fields of iron ore and coal and the seats of the greatest commercial and industrial activity. It is not probable that any great impetus will be exerted in the direction of actual work on canals connecting the Mississippi Valley and the Great Lakes until the Panama Canal is completed and more attention is given to foreign trade. It would seem reasonable to think that the work of enlargement of the Erie Canal, now about to be undertaken by the State of New York, will also tend to develop more interest in the possibilities of inland navigation in the United States.

Only the Illinois and Mississippi Canal, shown on Plate XV, has been built within the last ten years, and this canal, with that at the "Cascades" and that proposed between Celilo and the Big Eddy, Columbia River, Oregon, represent largely the practice in the United States during that time.

The following is a brief description of the salient features of these three projects, prepared by the engineers in charge of the works:

Illinois and Mississippi Canal.

"This canal is under construction with the object of furnishing a navigable waterway between the Illinois River near Bureau (or Hennepin) and the Mississippi River near Rock Island. It forms a part only of the proposed navigable waterway from Lake Michigan to the Mississippi River.

"It is built in four sections:

"*Section 1.*—'Eastern Section' runs from Illinois River to Feeder Junction, a distance of 28 miles, and has 21 locks, representing a difference of 196 ft. in water levels. Maximum lift of lock is 12 ft.;

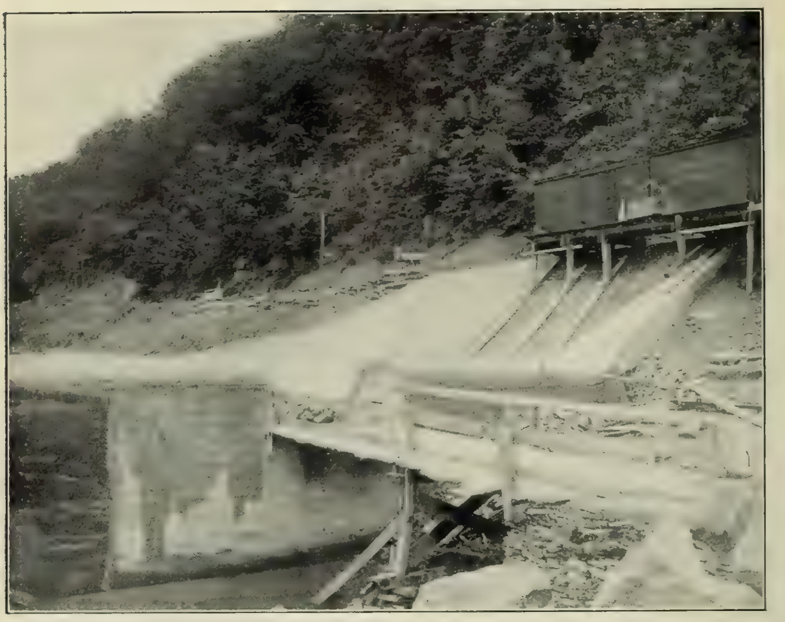

FIG. 1.—SLOPING ABUTMENT.

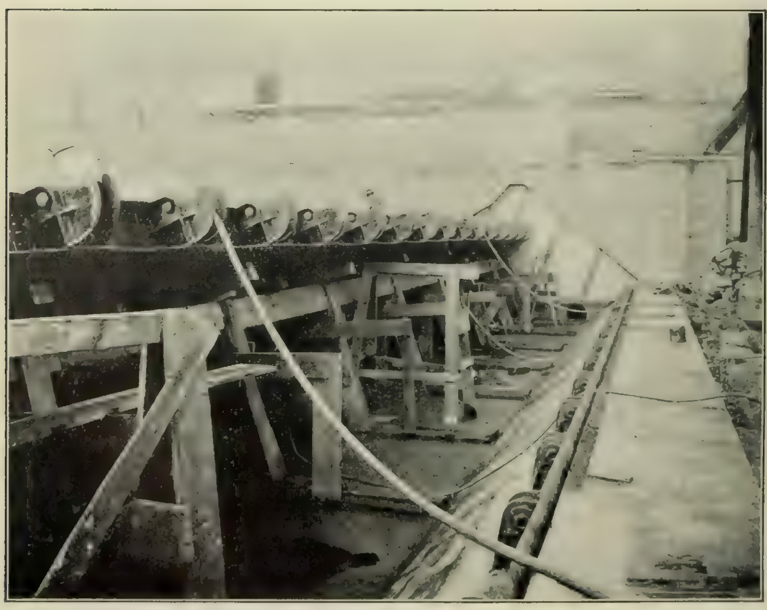

FIG. 2. BEAR-TRAP DAM.

minimum, 8 ft. There are three aqueducts and several bridges, both for highway and railroad carriage.

"*Section 2.*—'Western Section' runs from Feeder Junction to Rock River near Colona; has 8 locks with a combined lift of 75 ft. There are 5 aqueducts and several bridges and culverts. This section is 34 miles long.

"*Section 3.*—'Feeder' line is to be navigable and runs from Rock River to Rock Falls or Sterling, south to junction with Eastern and Western sections, a distance of 29 miles. There is to be a dam (not yet designed) at Rock Falls and a guard lock, one aqueduct and several bridges and culverts in this section.

"*Section 4.*—From the junction of Western section and Rock River, the river is made navigable for about 8½ miles by the construction of a dam some 1 392 ft. long, located near Milan, and the slack-water navigation goes in a canal around the lower rapids of Rock River at this place. There are three locks and two drawbridges, also several culverts and two sluices. The water is supplied to the canal through two circular sluice gates (Tainter gates). Difference in levels at Rock River above dam and Mississippi River is about 18 ft.

"This section was opened for navigation April 17th, 1895.

"*Construction.*—The canal is 80 ft. or more wide at water line and 7 ft. deep.

"The locks are 35 ft. wide and 170 ft. between miter sills.

"*Locks.*—Of the 34 locks built, 20 have miter gates throughout. The remaining 14 have lower gates constructed on the miter type, the upper gates turning around a horizontal axis (tumble gate), being lowered by the hydraulic pressure from the difference in levels of upper and lower pools at the respective locks, working on a maneuvering tail on gate. The gate is lifted by its buoyancy. This type of gate was invented by Major W. L. Marshall. An experimental gate of this type was built and successfully operated by Major J. H. Willard.

"The gate is absolutely tight when up. It works smoothly and rapidly and responds readily to the manipulation of the operating valve.

"The locks are built of concrete on a foundation of grillage resting on piles when found necessary.

"*Aqueducts.*—The aqueducts are 40 ft. wide and are built in spans of 35 ft. center to center of piers. The piers are like all other masonry on the canal, made of Portland cement concrete. The trough is made up of steel beams lined with plank. The aqueduct on the Feeder line crossing Green River is provided with two emergency gates, one in each abutment. These gates are of the Des Fontaines type and raised by the hydraulic pressure in aqueduct, and lowered by the preponderance of weight of upper leaf. The gate operates against the current created by a possible breach in the embankment.

"The summit level is about 40 miles long and the aqueduct is 23 miles south of Rock River. In case of a breach, a considerable amount of water may be saved by raising one of the emergency gates.

"*Culverts.*—Some of the culverts under the canal are built like an inverted siphon, and are so arranged that water from the canal above may be let into culvert and flush same, thereby removing accumulated sediment. Culverts are both single and double pipe, or arch construction.

"*Bridges.*—All bridges are fixed with the exception of two drawbridges near Milan which swing on center piers, and some bridges located near locks. The latter are lifted high enough over the lower pool to give the standard clearance of 17 ft. adopted for the canal.

"There is also one pontoon bridge."

Canal Around the Cascades, Columbia River, Oregon.

The improvement of the Columbia River at the Cascades, Oregon, and between the foot of Dalles Rapids and the head of Celilo Falls, Oregon and Washington, has presented some of the most difficult problems in river engineering. The scope of this paper, however, precludes a description of the many difficulties and the various projects proposed to overcome them. The work in accomplishment of this, completed within the past ten years, has been confined essentially to the construction of a canal around the Cascades, of which the following is a brief description:

"*Canal.*—The canal lies in a straight line across the convex, or Oregon bank, of the Columbia River and flanks the upper or principal rapids at the Cascades throughout their full length of about a half mile. It has an available depth of 8 ft. below extreme low water and a least width of 90 ft., the excavation being through the loose sand and gravel intermingled with large basaltic boulders of which this bank is composed. Below this loose material there is encountered a native conglomerate bed rock of poor quality, hard enough, while in place and protected from the air, to require blasting to remove it, but disintegrating easily when exposed to damp air. The general level of this rock being above that of the bottom of the canal, the excavation was for a large part of its depth made through this bed rock. The canal walls and masonry of the locks, with the exception of a portion of the wall on the south side of the upper entrance, are all founded on this rock, which was first leveled and then covered with a layer of concrete. The sides of the canal, outside the limits of the locks themselves, are revetted through-

PLATE XVIII. VOL. LIV. PART F.
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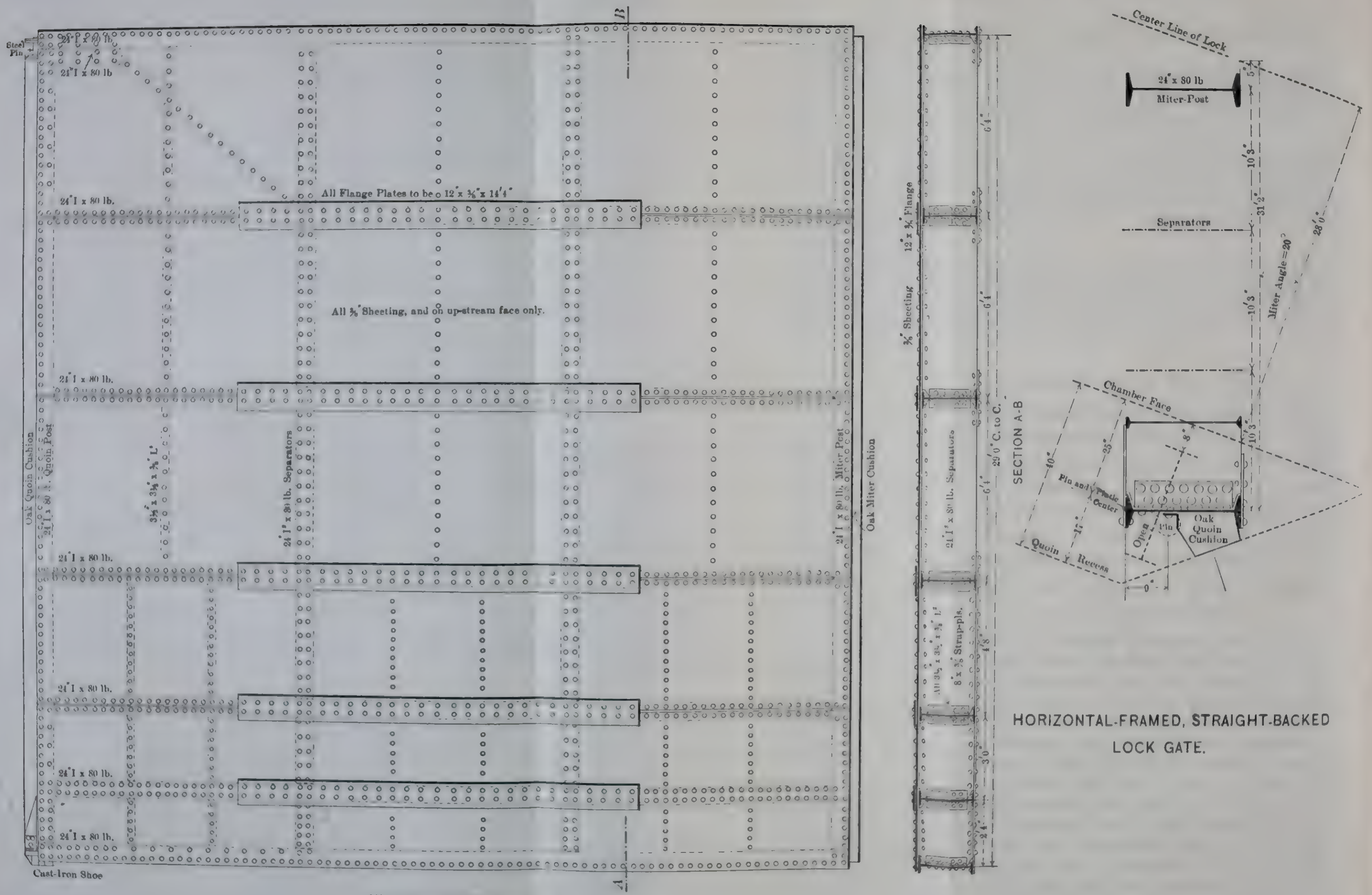


UP-STREAM ELEVATION

HORIZONTAL-FRAMED, STRAIGHT-BACKED LOCK GATE.

out the entire length of the canal with cut-stone masonry laid in mortar on a batter of 12 vertical on one horizontal and backed with random rubble laid dry. These walls rest on a course of concrete founded on bed rock and rise to a height above low water of 20 ft. at the lower end and 14 ft. at the upper end, these heights corresponding approximately to the same stage of water. The canal entrances are funnel shaped, the minimum width of each being 90 ft., the maximum width of the upper entrance being 250 ft. and the maximum width of the lower entrance 140 ft. The bed rock at the bottom of the canal at both the upper and lower entrances to the locks is covered with a layer of concrete 12 in. thick. The banks of the canal above the canal walls and above the locks are graded back to a slope of 1 vertical on 1 horizontal at the upper end, and 1 vertical to 1½ horizontal at the lower end, and are protected up to extreme high water level by a pavement 3 ft. thick formed of carefully placed basaltic blocks laid without mortar.

"*Locks.*—The locks are 90 ft. wide, and have a least available depth of 8 ft. at low water. They are 462 ft. in available length, the upper lock being 514 ft. between hollow quoins and the lower one 521 ft. This capacity was needed to accommodate at one lockage one towboat with three barges of the ordinary size which it was deemed desirable to provide for. The lower lock has a lift of 24 ft. at low water, the upper one, being used only during high stages, has no lift wall. The locks are available, however, for all stages of water below a 42-ft. rise at the lower end of the canal, although the steamboats in use up to the present time do not attempt to navigate the river at stages above a corresponding height of 36 ft. A rise of over 42 ft. is very exceptional so that the locks may be said to be practically available all of each year.

"The lock walls are built of Portland cement concrete resting on the bed rock, the lock and lift walls being all faced with cut-stone masonry laid in mortar.

"*Gates.*—The gates are of steel throughout, cylindrical in shape, and are built up entirely of plates and angles except the forged steel pintle-sockets."

Proposed Canal between Celilo, Oregon, and Big Eddy, Columbia River.

"*General Description of Proposed Line.*—The route finally selected, and on which the estimate herewith is based, commences in the rock on the Oregon shore at a point just below Big Eddy and runs along the rocky ground between the railroad and the river. At the head of Five-Mile Rapids it passes into sand and gravel for a distance of about 12 400 ft., where rock is again encountered and through which it continues for about 7 900 ft. until it enters the second stretch of sand and gravel at the 'Willows.' At the head of Ten-Mile Rapids, about 6 400 ft. above the 'Willows,' the line strikes the basalt again and keeps on between the Oregon Railroad and Navigation Company's track and the river until finally the low place just below Celilo Falls is reached. Here it is proposed to wall off the canal from the river by a high masonry wall founded on rock. This special wall will form a large basin in the canal. From this basin the canal passes into the upper lock, and finally enters the river in the rock and gravel just above Celilo Falls. The total length of this line will be about 45 000 ft.

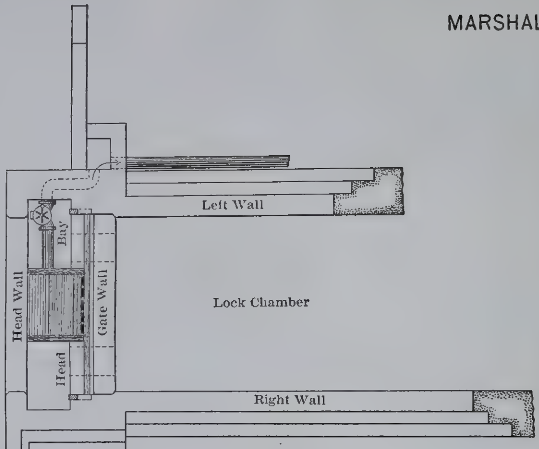
"*Passing Places.*—Throughout the length of the canal, and situated about one mile apart, basins are provided of sufficient size to admit of boats passing one another. In order to save excavation in their construction where possible, these chambers are to be formed by widening the canal where the ground is already more or less below grade.

"*Curvature.*—The minimum curvature adopted, except at unusually wide places, is limited to a radius of 955 ft. and boats that can pass through the locks should have no great difficulty in making fair speed.

"*Elevations and Water Levels.*—From data obtained from survey of 1879, adopted extreme low water at the lower end of the canal is found to be at reference (9) and the elevation of the same stage immediately above Celilo Falls is at reference (89), a difference of 80 ft.

"As the canal is to obtain its water supply from the Columbia River immediately above Celilo Falls, the elevation of the water level in the canal at extreme low water cannot exceed reference (89), and as it is desirable to keep the canal as high as possible in the upper portion to reduce the height of the river retaining walls, reference (89) is adopted for the elevation of the water surface at extreme low water from Celilo to a short distance below the head of Five-Mile Rapids, a distance of about 7 miles. Here a single lock drops the elevation to reference (78), which is carried until it is brought down by the tandem locks at the lower entrance to the level of the river at the foot of Big Eddy. The walls of the upper line of the canal and the middle lock are raised sufficiently so that an elevation of the water surface to reference (93) may be allowed between the Celilo and Middle locks. This is chiefly to counterbalance a possible upward pressure under the bottom lining of the canal where it is situated in porous sand or gravel, which would otherwise be caused when the river approaches the limit of navigation by percolation through the permeable foundation. This arrangement also obviates the necessity of lockage at the upper entrance until the river at Celilo is above reference (93), and at the same time gives an increase of depth a large part of the time in the long upper level. (See Fig. 19.)

MARSHALL'S AUTOMATIC UPPER LOCK GATE.



PLAN

Fig. 1.

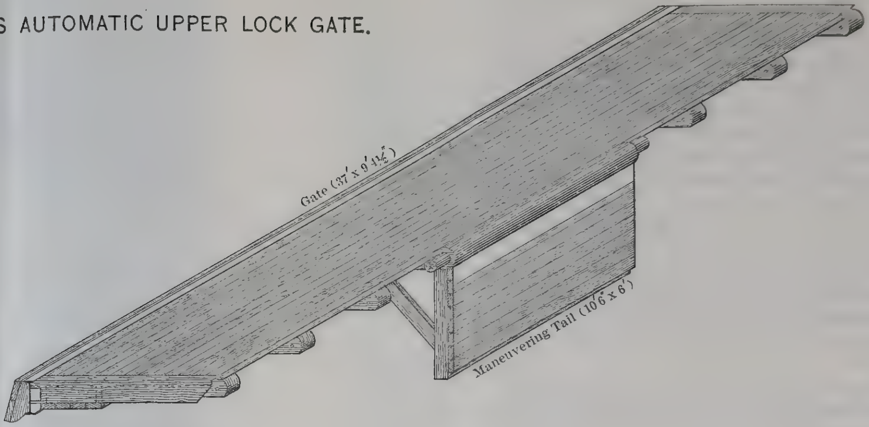


Fig. 5.

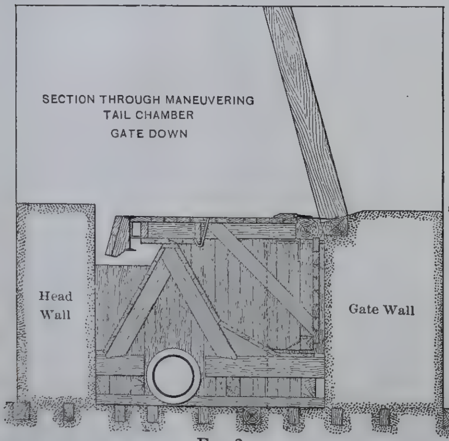


Fig. 2.

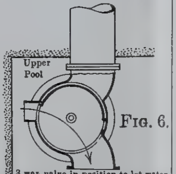
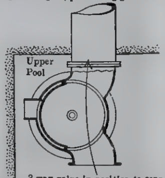


Fig. 6.

3 way valve in position to let water in from upper pool under maneuvering tail of gate, permitting gate to rise.



3 way valve in position to connect lower pool with maneuvering tail chamber and to lower the gate by pressure of upper pool on upper side of maneuvering tail.

Fig. 7.

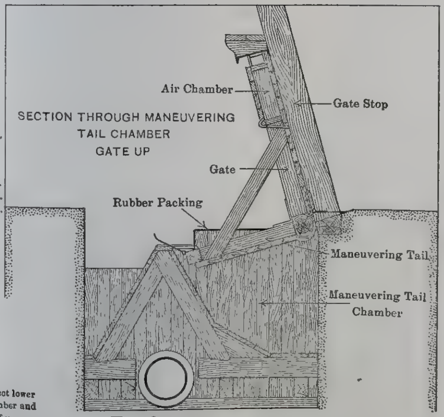
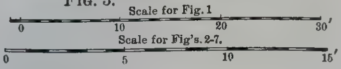


Fig. 3.



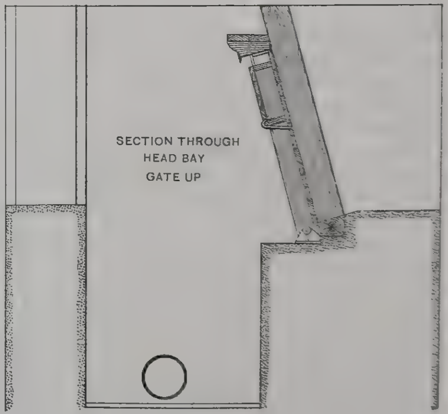
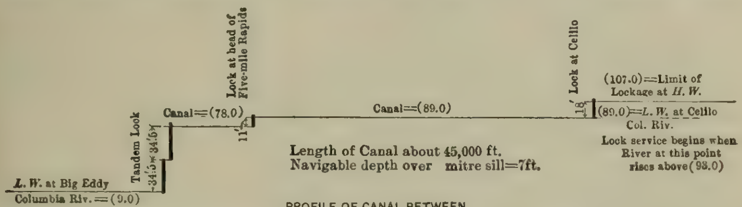


Fig. 4.

"*Flooding of Canal.*—The average summer high waters of the Columbia River will completely overflow the canal. To regulate the entrance of the flood water as the river reaches the stage of 38 ft., at Cascade Locks, so that it shall not come over the walls towards its up-stream end first, the slope of the river retaining walls is made somewhat greater than that of the water surface corresponding to this 38-ft. stage, thus allowing the flood water to enter the canal first at the lower end of both sections.

"*Sluice-ways.*—For the purpose of sluicing out of the canal into the river any sand or river sediment which may become deposited in it, two openings, closed wth suitable steel gates, are provided in the rock or river walls, one near Ten-Mile Rapids and the other just below the head of Five-Mile Rapids.

"*Locks.*—The elevation of the river surface just above Celilo Falls rises to reference (106.3) when the stage is 38 ft. at Cascade Locks. The plan provides for a lock at the upper entrance just above Celilo Falls with a capacity of lift of 17 ft. to pass boats between the canal and river until the limit of navigation is reached. Another lock is to be situated just below the head of Five-Mile Rapids with a lift of 11 ft. At the lower entrance is to be a tandem lock to overcome a total lift of 69 ft. at times of extreme low water, each lock to have a lift of 34½ ft. All the locks are to be 40 ft. wide and capable of passing boats 250 ft. long.


Lock at head of Five-mile Rapids
Lock at Celilo
(107.0)==Limit of Lockage at *H. W.*
Canal==(78.0)
Canal==(89.0)
18'
(89.0)==*L. W.* at Celilo Col. Riv.
Lock service begins when River at this point rises above (93.0)
Tandem Lock
34.5'
34.5'
11'
Length of Canal about 45,000 ft.
Navigable depth over mitre sill=7ft.
L. W. at Big Eddy Columbia Riv.==(9.0)

PROFILE OF CANAL BETWEEN
CELILO AND BIG EDDY—COLUMBIA RIVER, OREGON

FIG. 19.

"*Canal Lining.*—Where the canal is situated in sand or gravel it is proposed to line it on the sides with masonry walls in mortar, 2 to 3 ft. wide on top with batter on one side of 2 on 1. The bottom is to be lined with concrete 1 ft. thick. Lining was not thought necessary for sections in solid rock. As a relief against possible upward hydrostatic pressure on the concrete bottom of the canal at stage of the river approaching the limit of navigation in that stretch of the canal next above Ten-Mile Rapids, two rows of 6-in. diameter tile drain pipe are to be laid under the concrete with T-joints and iron weep valves at intervals opening into the canal.

"*Walls.*—Where situated on rock the walls are designed to be of rubble-masonry in mortar and to be carried up at least 2 ft. above either the water level in the canal or the level of the river outside at the limit of navigation. All walls are given an ample factor of stability against any possible pressure to which they may be subjected. A high wall, as already stated, is required just below Celilo Falls. It will be about 1 200 ft. long and founded on rock at low water by building a low coffer-dam. The foundation of this wall is not expected to be below reference (58) at any point and its top is to be at reference (106). A shorter special wall opposite Station 27 + 50 to Station 31 will have to be as high as 80 ft. in one place to reach a rock foundation. Both of these special walls are itemized in this estimate.

"*Protection of canal where it leaves the rock and passes into the sand, especially just above Five-Mile Rapids and Ten-Mile Rapids.*—At Five-Mile Rapids it is proposed to carry the outside lining wall down from 20 to 24 ft. to rock or gravel foundation. The sand between the canal and river will be thoroughly riprapped and in the most exposed places hand paved with waste rock from excavation. For purposes of estimate the outside wall was carried down below the canal bottom its full width, but without batter. This gives a stronger wall than is necessary for a core wall only, and yet hardly strong enough for a retaining wall if all the sand on the outside of it should be washed away. It is believed that the riprapping will prevent this, especially as there is but little, if any, current at higher stages when the river reaches or covers the projection.

"The part of the canal where it leaves the rock just above Ten-Mile Rapids is also in sand of very great but unknown depth, but it is thought that the canal can be made secure by riprapping and paving the river bank in the manner just described. The canal for the few hundred feet where these conditions exist could, of course, be supported on a grillage founded on piles, but estimate on this plan was not made. The current of the river at both of these places is checked at high stages by the gorges at Ten-Mile and Five-Mile Rapids, and at low stages the walls are completely uncovered.

"The other two places where the canal leaves the rock and enters the sand are at greater distance from the river and can be protected with a less amount of ordinary riprap.

"*Wooden Lining and Fenders.*—That part of the canal in rock cuts of considerable height was estimated to have 1 ft. extra of rock removed from each side and to be lined with heavy wooden fenders fastened at intervals to the rock.

"*Protection of the canal against blowing and drifting sand.*—The rapid drifting of the sand under the influence of the violent winds which prevail, especially in the spring and autumn, if not controlled will be a serious obstacle to maintenance of the canal throughout the two sand and gravelly stretches. The test pits dug during the survey filled very rapidly with sand. It is thought,

PLATE XX. VOL. LIV. PART F.
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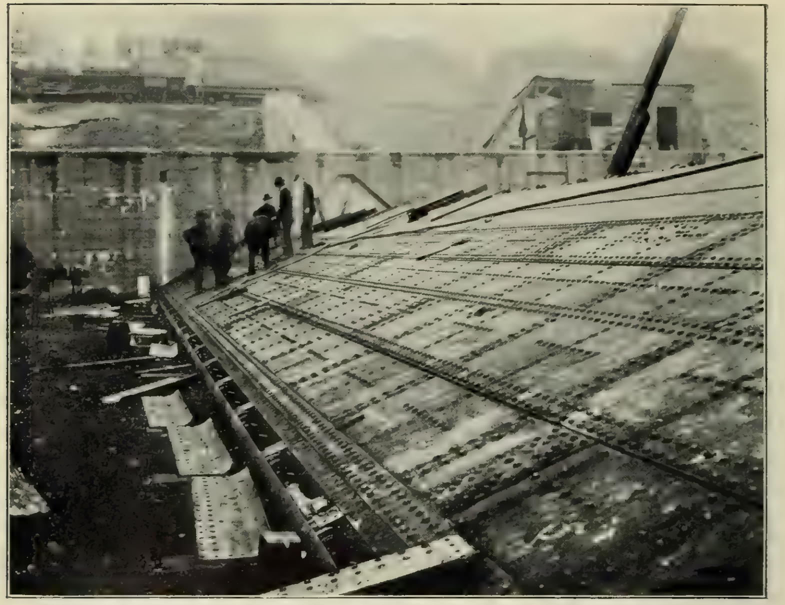


FIG. 1.—BEAR-TRAP DAM.

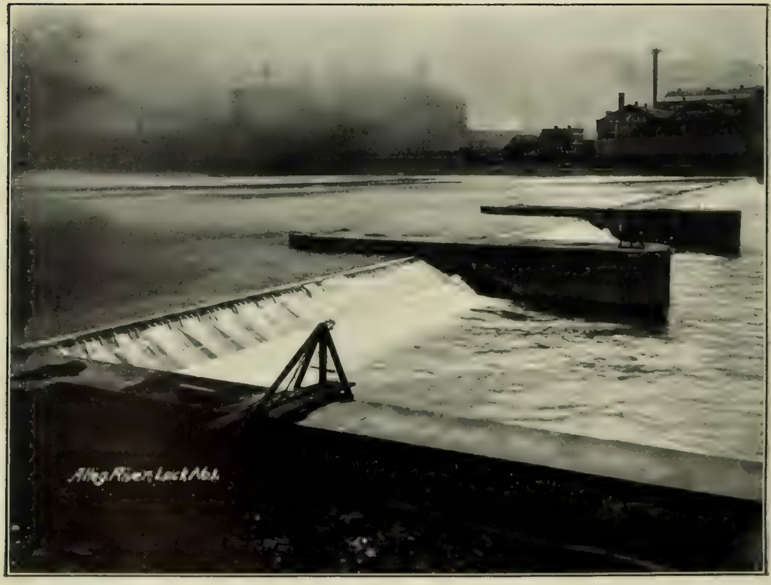


FIG. 2.—LOCK NO. 1, ALLEGHENY RIVER.

however, that by irrigating the sand by means of movable pumps, taking water from the canal itself, that the greater part or at least a wide strip on each side of the line can be reclaimed and support a growth of grass, bushes and willows, and thus arrest the sand movement into the canal. The total area of the sand between the railroad and river does not exceed 850 acres, which it would seem possible to take care of for a reasonable expense.

"*Dimension of Canal Prism.*—The canal prism is taken at 65 ft. wide on the bottom and in figuring the quantities a slope of 4 on 1 was allowed for rock cuts, and in the sandy portion a proper allowance was made for extra excavation for side walls and concrete lining. The canal is designed to be 8 ft. deep at low water with 7 ft. over the miter sills. A grade of about 1 ft. is given the bottom between the Celilo and Middle Locks."

Canalized Rivers.

Locks with Fixed Dams.

The function of lock walls and of dams being essentially the same at all times, no important changes have been made in their general design. The material used in their construction has been largely changed, in the case of lock walls, from cut-stone masonry to concrete, and in the dam, from timber, in many instances, to concrete, especially where timber has become expensive or the water supply short. Both the lock walls and the dam when of concrete are ordinarily built in monoliths 20 to 30 ft. long and generally the full height of the wall or dam. In some instances there are as many as three monoliths from top to bottom in the lock wall of the lengths specified above. The monoliths are keyed together and keyed to the foundation in the manner shown on Figs. 1 and 2, Plate XVI.

In some of the earlier concrete locks, built in monoliths, the various monoliths were not keyed together vertically, with the consequence that water was continually seeping through the vertical joints of the land wall, giving rise to an unsightly condition and facilitating the destruction of the wall gradually by frost. A comparison as to ultimate durability of stone and concrete in lock construction has not yet been obtained. The destruction of stone on the inside of lock walls by frost between the pool lines leads to the belief that, with especial care in reducing the porosity of concrete on the inside faces of lock walls, it may be given an element of superiority over stone.

The abutment rising vertically from the end of the dam to a height about equal to that of the top of the lock wall, and connected with the bank above and below by wing walls, has given way to a sloping abutment conforming as far as practicable to the natural slope of the bank, thus removing an obstruction to a flow of water that gives rise to eddies and consequent scouring below, an eddy current being more destructive to the bank than a direct current of the same velocity. (See Fig. 1, Plate XVII.)

Lock Gates.—The material used in lock gates in the last ten years has been largely changed from wood to steel. There are two types of miter-gates with straight backs in general use for small and medium-sized locks. These types are:

First: Gates with leaves framed horizontally, Plate XVIII. In this type the load is assumed to be distributed to horizontal members in proportion to their depth below the water surface, and thus may be treated as beams acted upon by a uniform load applied normally.

Second: Gates with leaves framed vertically, Fig. 20. In this type the load is transmitted by the sheeting to a system of verticals, which are supported by the miter-sill at the bottom and by a strong frame near the top of the leaf. No intermediate horizontals are used for the purpose of carrying the load. The advantage claimed for the design is that a large portion of the pressure, sometimes as much as two-thirds, is borne by the miter-sill. Where the length of the leaf is much greater than its height, a saving of weight may result in adopting this type of gate instead of the first type mentioned.

A combination of these two systems is sometimes adopted, facilitating to some extent the construction of the gate, due especially to the possible equal spacing of the horizontal members.

An unique gate, shown on Plate XIX, is said to be in successful use as an upper gate in some of the locks (width of lock, 35 ft.) in the Illinois and Mississippi Canal.

The larger locks, such as those in the St. Mary's Falls Canal, Cascade Canal, and those on the Ohio River, have, for each system, a special form of gate. In the St. Mary's Falls Canal, the lock gates are of the miter type and have curved upper faces and double skins. The gates in the Cascade locks are steel miter-gates, cylindrical in plan, with a single skin. Those on the Ohio rest on wheels, and are pulled back and forth across the lock by power.

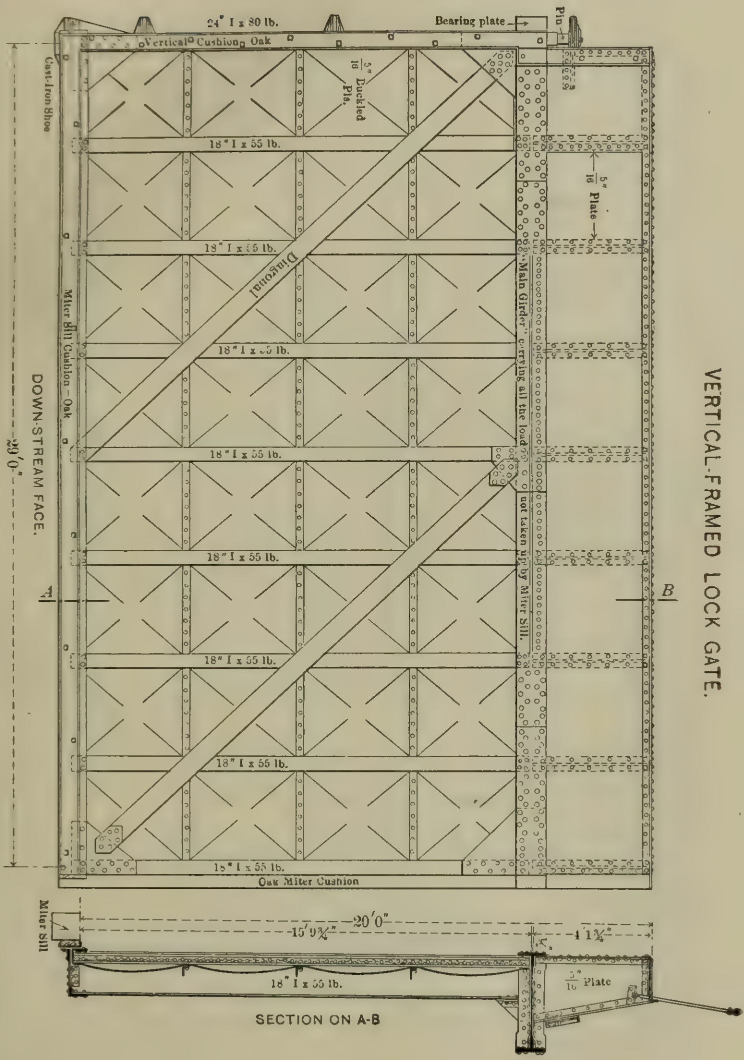


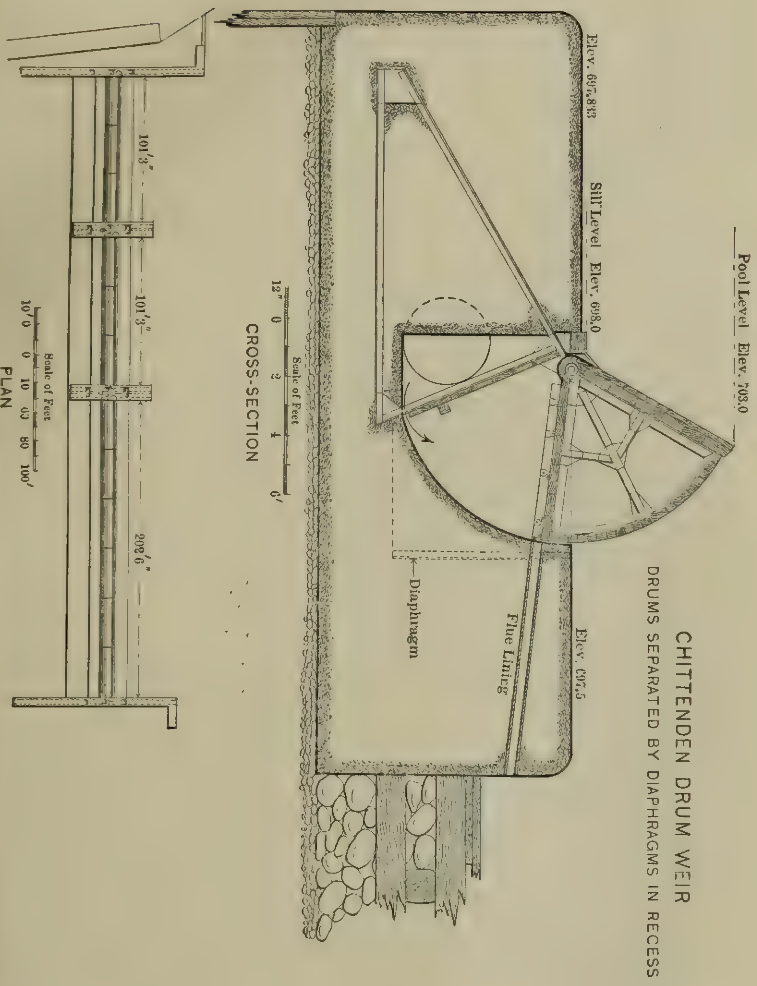
FIG. 20

VERTICAL-FRAMED LOCK GATE.

All of these gates have been described in previous publications. The Ohio River locks are 110 ft. wide and the gate maneuver, as already described, has been very satisfactory.

The continual demand for increase in depth of navigable streams once improved, and the impracticability, in many instances, of increasing the height of the old permanent dams on some of the improved streams, have led to the adoption of an automatic movable top for fixed dams. Most prominent among those proposed is the Chittenden drum-weir, Fig. 21. It was not thought practicable to construct this drum in sections greater than 75 ft. in length, and in cases where navigation over the dams was possible when the locks were flooded, the existence of piers, 75 ft. apart, on the crests of the dams, made such navigation impracticable. This led to the modification of the original plans concerning this weir, as shown on Fig. 24, which modification was to place steel diaphragms across the drum-chamber, taking the place of piers, making the drums of any convenient length. These diaphragms were made strong enough to stand the water pressure if the drum lifts in one section and not in the section contiguous thereto. The only limit to the distance between the piers seems to be the ratio between the water entering the culverts and the leakage. A Chittenden drum-weir with the above modification is now being constructed on the Ohio River, taking the place of a portion in height of the fixed dam between Davis Island and the shore. Its special function in this case is to act as a weir for the Chanoine dam across the main channel of the Ohio River, and it is to some extent an experiment in determining the most efficient movable top for the dams on the Monongahela River, the rebuilding of which with movable tops has been commenced.

The winters in Western Pennsylvania are quite severe, and it is hoped that an automatic top can be developed which will be effective in causing the ice to run out of the several pools into those below, it being an essential to the many steel plants in and about Pittsburg that navigation in the Monongahela River be continuous, or as nearly so as practicable. An attempt is made in this river to keep the locks in operation when the ice in the pools is sometimes 14 in. thick. The continual movement of boats keeps the ice broken. If this broken ice could be forced down stream about twice a week it would greatly improve general navigation and facilitate locking.



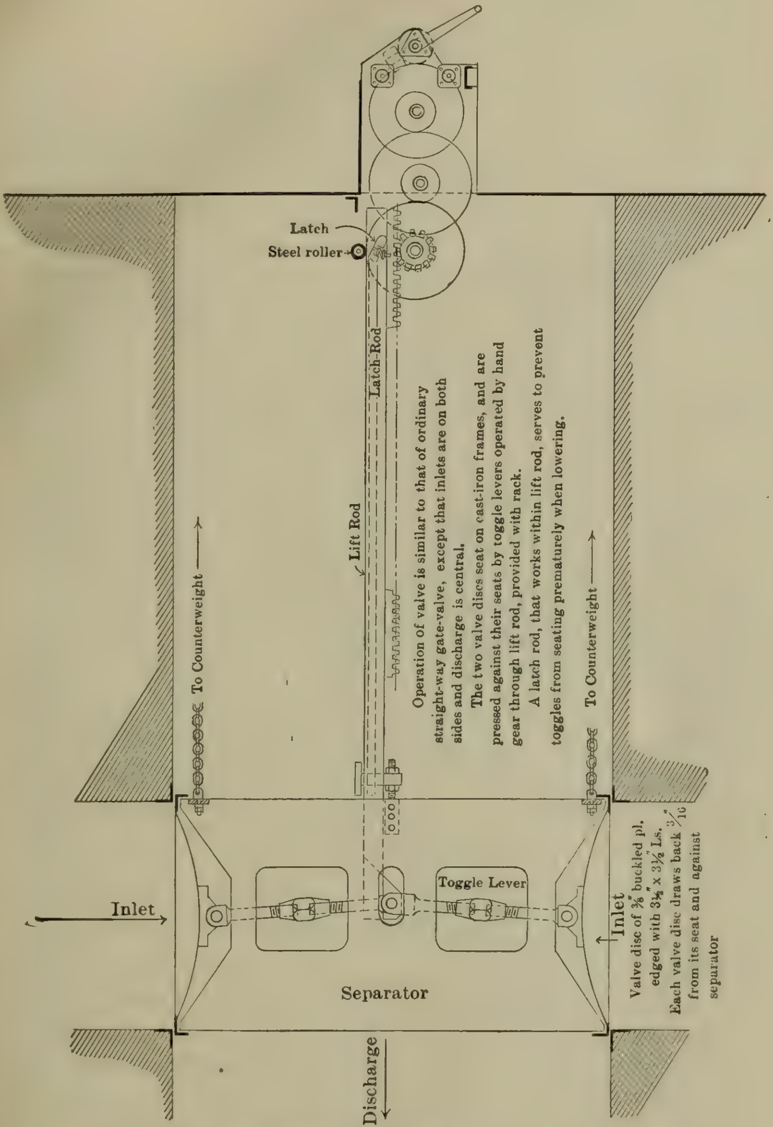
CHITTENDEN DRUM WEIR
DRUMS SEPARATED BY DIAPHRAGMS IN RECESS

FIG. 21.

This broken ice, flowing into the forebay as the locks fill, and piling up behind the gates, is the source of much trouble. In some of the new locks for the above service, water for filling the lock is taken from the outside of the guard wall, thus filling the lock without creating any current in the forebay. Valves are placed in the upper gates for the purpose of completing the filling when there is a material slope in the river from the upper end of the guard wall to the valve intakes.

Locks and fixed dams are massive structures, but there is one very weak element in the system, and that is the gate. It is impracticable to construct a gate of sufficient strength to resist a collision with a boat coming against it with any speed. As an accident of this kind is serious, and causes a considerable delay of traffic if there be only one lock at each dam, the practice on the Monongahela River, which probably has a greater commerce than any other stream of the same capacity in the world, is to construct at each dam a lock with two parallel chambers. The Monongahela River in the low-water season has as small a discharge as 166 cu. ft. per sec., and there were transported on it in the year ending June 30th, 1903, 11 369 814 tons of freight, and this through locks built 20 to 60 years ago. This freight movement shows the possibility of navigation with a fixed-dam system, and that it has not been demonstrated by any means that the day of the fixed dam is past. In fact, it is the writer's opinion that no movable-dam system would permit of a similar use of such a stream, the fall per mile being about 0.7 ft. on the lower 80 miles of the river, and about 2 ft. per mile for 45 miles above said portion, the winters quite severe, and the low-water discharge that previously recited. With new locks having parallel chambers of the same size, and of such capacity as to pass the average-sized tow at one locking, the capacity of the system will be almost trebled. That is, with a fixed-dam system more than 30 000 000 tons of freight can be handled on a stream which at times has a discharge of only 166 cu. ft. per sec. After sixty years of slackwater in the Lower Monongahela River, very little general silting up of the pools is noticed. This same is thought to be true of slackwater systems built about the same time on the Green, Barren, Kentucky and other rivers.

Valves.—As far as the writer knows, no distinctively new valve has been developed within the last ten years, unless it be that shown



Operation of valve is similar to that of ordinary straight-way gate-valve, except that inlets are on both sides and discharge is central.

The two valve discs seat on cast-iron frames, and are pressed against their seats by toggle levers operated by hand gear through lift rod, provided with rack.

A latch rod, that works within lift rod, serves to prevent toggles from seating prematurely when lowering.

Valve disc of $\frac{3}{8}''$ buckled pl. edged with $3\frac{1}{2}'' \times 3\frac{1}{2}''$ Ls.
Each valve disc draws back $\frac{3}{16}''$ from its seat and against separator

BALANCED FILLING VALVE

FIG. 22.

by Fig. 22. This valve is in successful use at Lock No. 10, Monongahela River.

Movable Dams.

With fixed dams, boats lose considerable time at the locks when the water is at such a stage that they could navigate the open river if the dams were movable. Towboats with full tow have difficulty in moving their tow in and out of a lock with a fixed dam when the river is considerably higher than pool stage, but would be able to handle easily the same tow in the open river at a higher stage. On the Monongahela River, towboats can handle about twice as many barges when the river is at pool stage as they can safely place in the lock when the stage is 5 or 6 ft. above pool. The full tow at pool stage, however, could be handled safely at the higher stage if no locks had to be passed. This is probably the greatest advantage of movable over fixed dams in towboat navigation. Flood heights are somewhat increased by fixed dams. This increase, however, is generally over-estimated in streams having slopes suitable for movable dams, and where the lift does not materially exceed 12 ft., or, say, one-third the height of maximum floods. These are some of the considerations which have led to the adoption of the movable dam in place of the fixed dam. In the upper or steep portions of rivers, where rises come quickly, and where the streams abound with drift and ice at certain seasons of the year, these movable dams are down for a considerable portion of each year, and only open-river navigation is available. A comparison of this great loss to navigation with the advantages and disadvantages of fixed dams, will determine, in many cases in the northern part of the United States, which system is preferable.

The economical transportation of freight is connected directly with the question of depth, and the question of the worthiness of the improvement of the stream depends on the expected commerce, of course, and directly on the question of attainable depth, in connection with the distance that products must be hauled on such stream to their ultimate market. In connection with low-water discharge, the depth may sometimes decide the character of the dam to be used in the improvement; that is, whether it shall be fixed or movable, and, if movable, the type.

Type of Movable Dam.—The Chanoine, Boulé and Needle types of dam have all been used more or less in the United States. The

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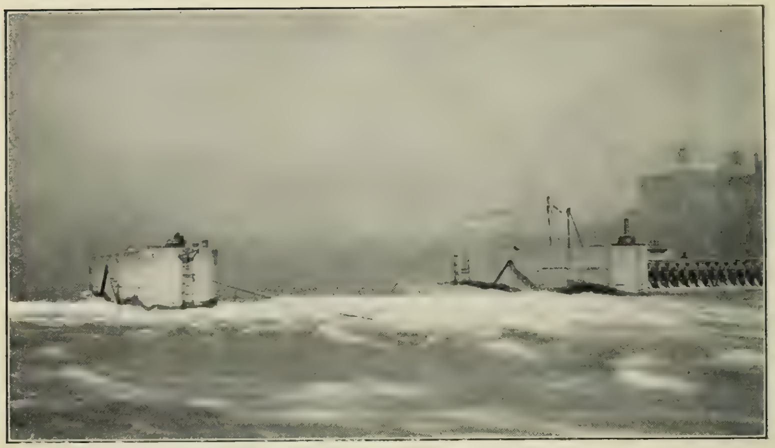


Fig. 1.—Herr Island Dam.

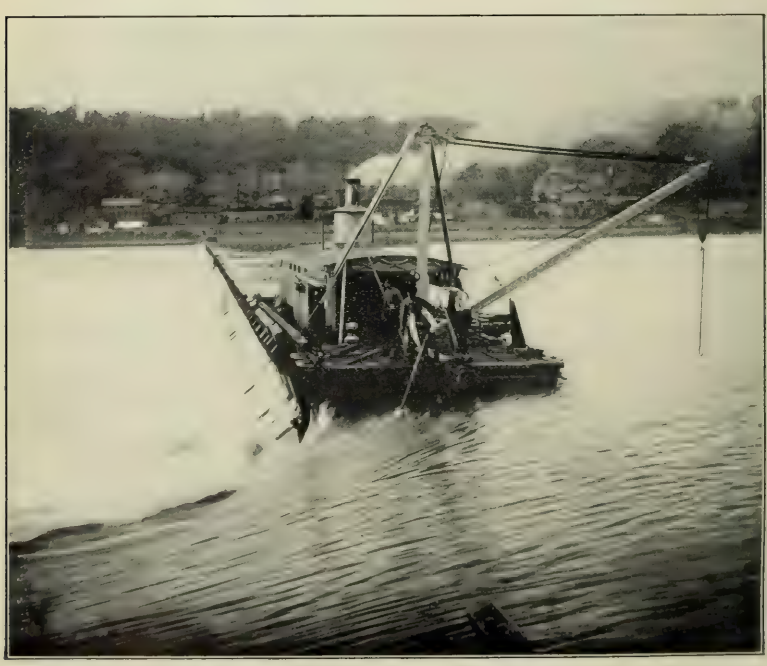


Fig. 2.—Maneuvering Boat, Opening a Dam.

Chanoine, with or without a service bridge, is, however, that in most general use. In connection with this type, as the main part of the dam and auxiliary thereto, bear-traps and drum-weirs are sometimes used.

The most extensive system of slackwater undertaken in the United States is that on the Ohio River. The locks in this improvement are 110 ft. wide and 600 ft. long in the clear. The dams will be from 1 000 to 1 800 ft. long, navigable pass from 600 to 800 ft. long. Two large tributaries of the Ohio, the Great Kanawha and Big Sandy, have been or are being improved by locks and movable dams. In the former, the Chanoine system of wickets with service bridge throughout is used. In the latter, a needle dam has been adopted.

Conditions that Determine Type of Dam.—First: Fluctuations in the water surface have a most important bearing on the type and method of operating movable dams. There are streams, or portions of streams, in the United States, which have comparatively regular seasons and slow rates of rise and fall of water surface, giving ample time for maneuvering, perhaps, any successful type of movable dam. In other localities, however, the streams are liable to quick floods at any time, frequently with little or no indication of their coming. Such conditions necessarily render imperative the adoption of a type of movable dam permitting quick and absolutely reliable operation.

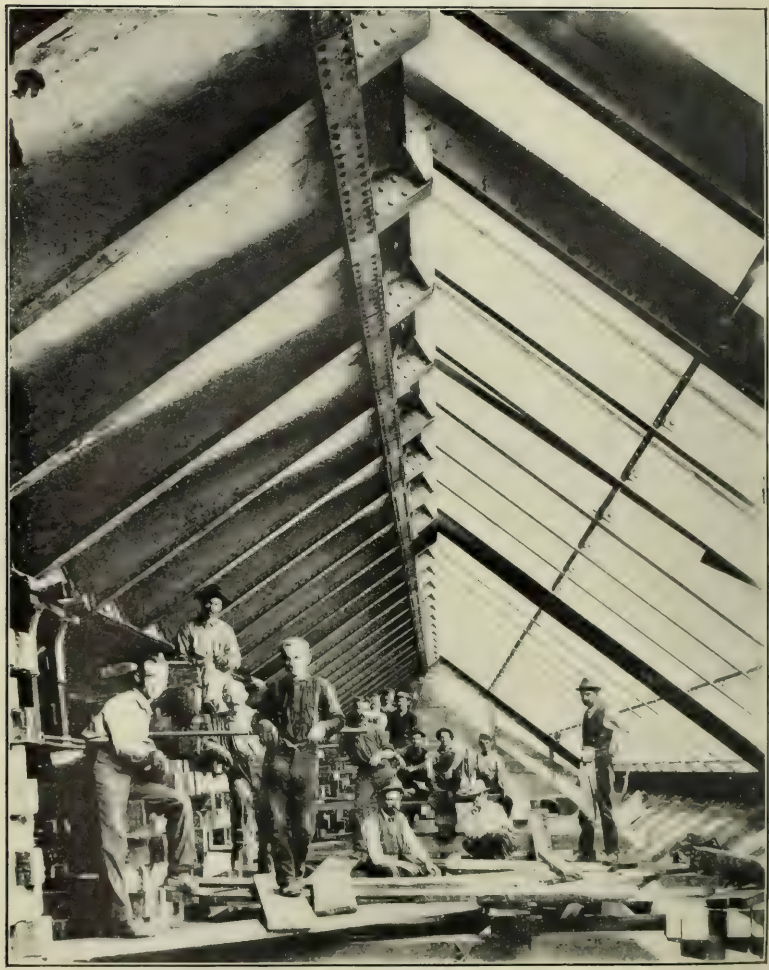
Second: The drift- and ice- bearing propensities of the stream are also important factors in determining the general type of dam. Large quantities of drift or ice in a stream subject to quick rises prohibit, in the general case, on large streams, the use of any form of dam which in any way facilitates the accumulation of such drift or ice in a manner seriously interfering with the maneuvering of the structure. Indeed, such drift and ice may altogether prevent the maneuvering, and, in fact, cause the actual destruction of the dam itself.

The above conditions exist in a marked degree on the Upper Ohio River, and they manifestly compel the adoption, on that or a similar stream, of the simplest and most compact form of dam; one devoid as far as possible of skeleton members.

Needle Dam.—While, in the opinion of the writer, this dam is excluded from general use in large streams which have much drift or ice, or in which movable dams must be manipulated quickly, still there are cases, such as that on the Big Sandy, in which this is apparently the best dam available. The distinctive feature practicable in a dam of this type is water-tightness, and its use is indicated on streams where the low-water discharge is exceedingly small, and where the stream itself is not too large, as already stated. Transporting and placing the needles in a long and high dam of this type are not conducive to quick operation.

Boulé Dam.—The most extensive use of this type of dam known to the writer is that at the Falls of the Ohio at Louisville, Ky., where about 1 250 ft. of it are in use and considered by those operating the dam system there as well suited to the service performed. The Ohio River at this place is exceedingly wide, and the rises come slowly and give ample time for the operation of the dam. Under such circumstances this type of dam is considered very efficient; its curtains being in several tiers, it is well adapted to pool regulation.

Chanoine Dam and Accessories as Applied to Upper Ohio River and Tributaries.—Originally, Davis Island Dam, No. 1 of the Ohio River series, was constructed throughout of Chanoine wickets. The navigable pass, without service bridge, was to be maneuvered only from a boat, and there were three weirs, with a bridge, intended for regulating the pool, removing drift and ice, and for the initial reduction of the pool in case a rise made necessary the lowering of more or less of the dam. It required only a few years' operation to demonstrate the incompetency of the weirs with service bridge. Frequently, during sudden freshets, so much drift assembled about the trestles of the bridge as to render its extraction prior to submergence of the bridge impracticable, and within one year and seven months the service bridges of Weirs 1 and 2 were wrecked. Accumulation of drift became such a source of danger in operating the dam that it was decided then to build a bear-trap chute to facilitate the passage of this drift. This bear-trap chute, 52 ft. wide, has now been in operation about 16 years. It has served successfully the purpose for which it was built, and, in addition, has demonstrated the advantage of such weirs in regulating pools. For this purpose, however, its utility was curtailed by its narrowness, which rendered it incapable of affording sufficient relief in the event of a material rise. Yet its usefulness had



BEAR-TRAP DAM.

been sufficiently established to justify its future application along more extended lines. Consequently in the erection of Dam No. 6 of the Ohio River series, which was the next to be placed under construction, provision was made for three automatic weirs of the bear-trap type, each 120 ft. in width. Two of these were erected, and the space originally provided for the third was eventually allotted for the trial of a new design of dam known as the "**A**-frame" dam.*

Simultaneously with the erection of Dam No. 6, Movable Dam No. 1, in the Allegheny River, at Pittsburg, Pa. (practically a part of the Ohio River System), commonly known as "Herr Island Dam," was also placed under construction. Its navigable pass is 500 ft. wide, composed of Chanoine wickets with a vertical height over sill of 13 ft. The remainder of the dam comprises two bear-trap weirs, each 94 ft. 4 in. long, one being 12, the other 10 ft. in height above their respective sills. This dam was put in operation in the spring of 1903. The period of its operations has been extraordinary in the number of rises, necessitating frequent maneuvering of the bear-traps in order to regulate the pool and dispose of drift and ice. After more than a year's trial they have proven their usefulness and satisfactory operation.

Briefly, in their general design the Herr Island bear-traps are of the simplest form of that type of dam. They are proportioned on the basis of the Chittenden-Powell formula, the theoretical ratio of hydraulic lifting force to downward pressure being 100 to 80. The foundations and piers are concrete, in which are constructed steel anchorages for the hinges. The hinges are of cast steel, spaced 5 ft. between centers. The lower gates were designed with a view to securing great rigidity. They were constructed entirely of steel, each gate having four longitudinal girders, and a cross-girt at each hinge. This structural framework is encased in a ⅜-in. water-tight steel skin. The upper gates are comparatively flexible longitudinally. They comprise a steel framework filled in with oak timbers. The weight of the movable parts of the larger bear-trap is 95 tons, and of the smaller one 82 tons, in water. Owing to their excessive weight, and the fact that they must of necessity be frequently raised when little head is available, a system of pipes for conveying air into the various compartments of the lower leaves was constructed in their foundations, the inflowing air expelling the water in the gates through open manholes in their underskins. By this means a pneumatic lifting force, 48.8 tons in excess of the weight of the larger pair of gates, less their water displacement, and 13.9 tons in excess of the weight of the smaller pair of gates, less their water displacement, may be applied within a few minutes whenever desired. To prevent the lower gates from passing the free edges of the upper gates, rigid cast-steel hooks were attached to the upper extremities of the cross-girts of the lower gates, which, at the proper elevation, engage in spring stops in the steel framework of the upper gates. (See Fig. 23, and also Fig. 2, Plate XVII, Plate XX, and Fig. 1, Plate XXI.) These weirs can be raised with a hydraulic head alone of about 5 ft., and pneumatically without the assistance of the hydraulic head, but their movement is greatly facilitated by the combined use of these forces.

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* *Transactions*, Am. Soc. C. E., Vol. XXXIX, p. 431.

In general design the 120-ft. bear-traps in Dam No. 6, Ohio River, are similar to those at Herr Island, but in construction they differ in that the spaces between the steel frames in the lower leaves are filled in with wood, and the use of air, but to a limited extent, is contemplated. The latter bear-traps, although built first, have been tested only once. These are now raised, but at this date, August 20th, 1904, the trial has not been sufficient to permit forming an opinion as to their effectiveness. (See Plate XXII.)

In former considerations of automatic weirs of the bear-trap type, reliance has been placed almost exclusively on hydraulic power as an operating force, and the most difficult question for solution has usually been how to secure that power for the initial movement of the weir at a time when a sufficient head due to the dam system itself was not available. If, in movable-dam construction, the raising of the mechanical part of the dam does not produce sufficient head to operate the automatic part, then some extraneous force must be applied or some mechanical device followed, such as an auxiliary dam above, to increase the head. Where an automatic weir constitutes only a small portion of the entire length of dam, the remainder of which is raised mechanically, no difficulty is encountered so long as the discharge of the stream through the automatic weir space makes head enough to operate the weir. Otherwise some auxiliary force becomes necessary. In the Herr Island bear-traps the pneumatic feature was inserted as essential,

PLATE XXIII. VOL. LIV. PART F.
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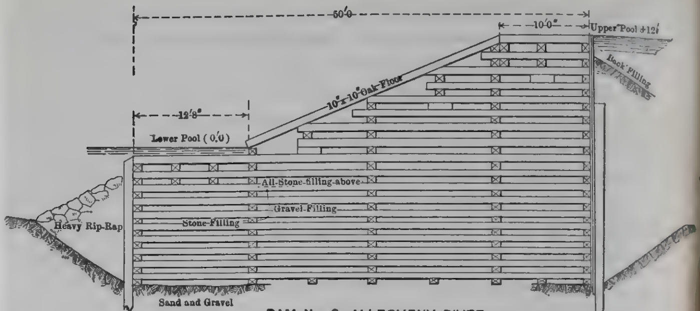
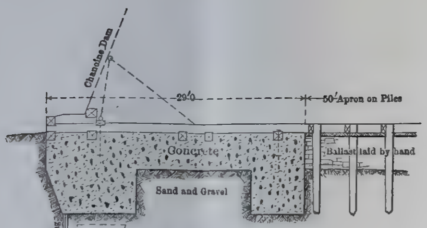
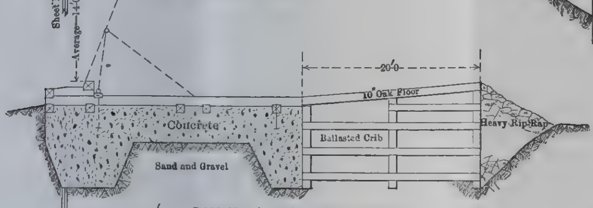


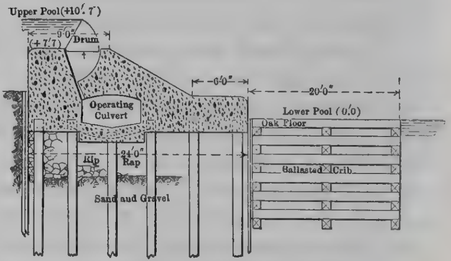
DAM No. 3. ALLEGHENY RIVER



DAM No. 6. OHIO RIVER

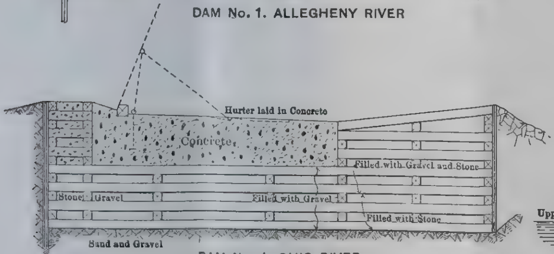


DAM No. 1. ALLEGHENY RIVER



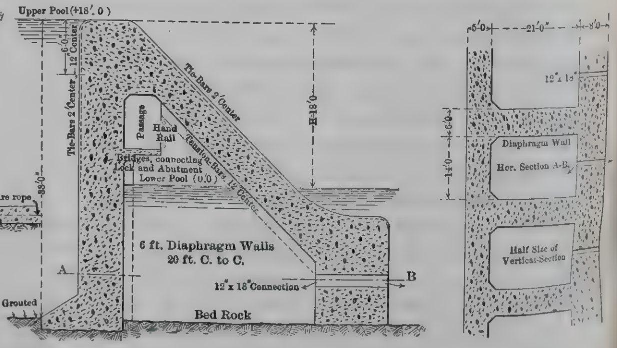
DAM No. 2. MONONGAHELA RIVER

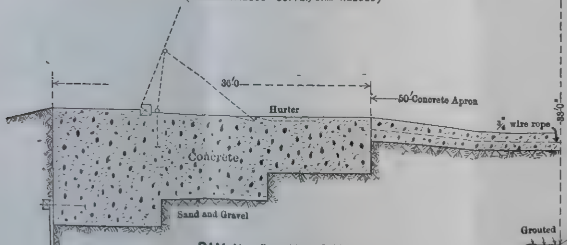
(NO EXTRANEOUS COFFER-DAM NEEDED)



DAM No. 4. OHIO RIVER

(NO EXTRANEOUS "COFFER-DAM" NEEDED)

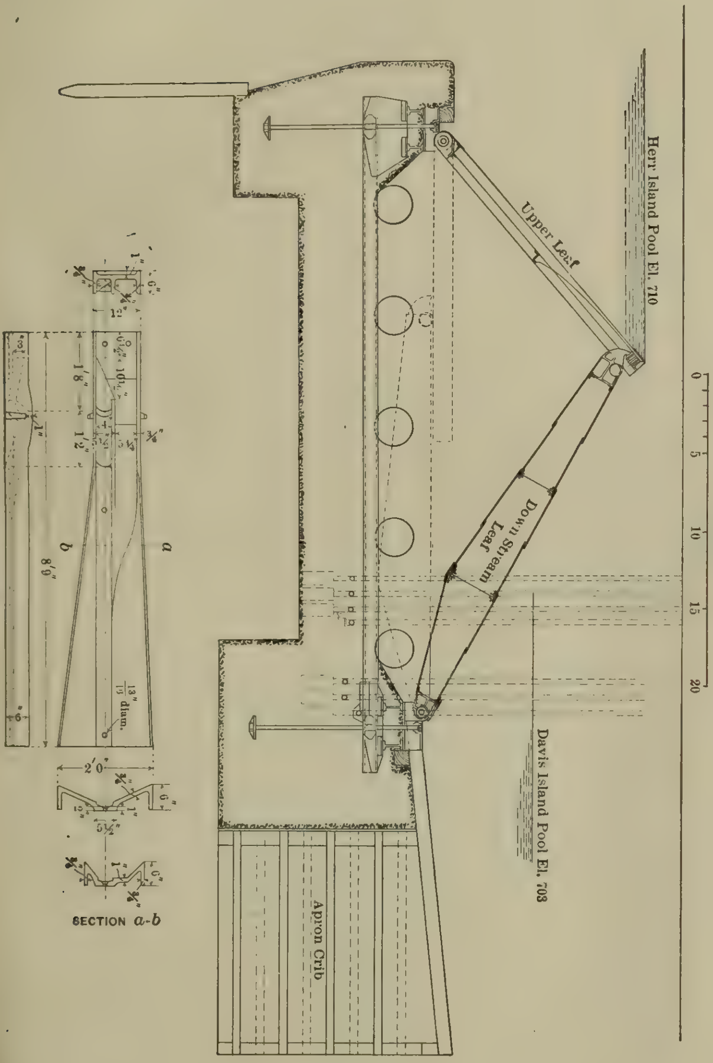




DAM No. 5. OHIO RIVER

DAM No. 11. KENTUCKY RIVER

BEAR-TRAP DAM. HERR ISLAND, ALLEGHENY RIVER.



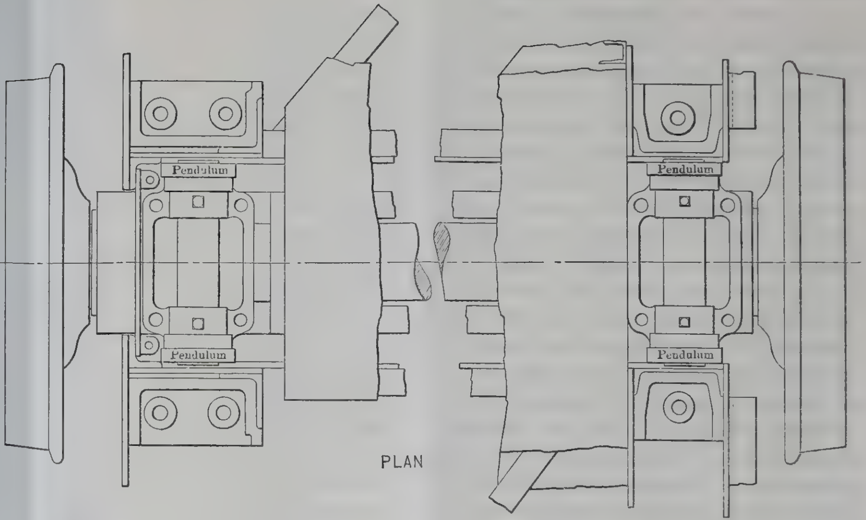
FIGS. 23 AND 24.

and its success has now been demonstrated so thoroughly as to leave practically no doubt as to its feasibility in general for the purpose, and its application as an essential element in bear-trap construction seems expedient in all cases where any doubt exists as to a sufficiency of head to operate the weirs without it. Calculations as to the head necessary to raise a bear-trap weir are generally made under the assumption that the space beneath the leaves is a closed vessel, which, of course, is in error, by the amount of leakage, the effect of which is to diminish materially the lifting force. Whatever be the method followed or material selected in building weirs of the bear-trap type, exceptional rigidity in the lower leaves is essential. Steel for such construction is objectionable on account of its weight and corrosiveness. Weight may be reduced by the use of wood; the life of a wooden gate will also be much longer than that of a common steel gate. Recently there has been designed a bear-trap weir, 102½ ft. wide, for Dam No. 2, Ohio River. In section the gates are similar to those at Dam No. 6 and Herr Island Dam, but their construction will consist of wood thoroughly bound and stiffened with heavy iron bands, rods and bolts. Being proportioned for materially increased hydraulic lifting force to downward pressure, and possessing much greater buoyancy, these gates should operate under a very small water head without extraneous assistance. The principal question respecting this wooden bear-trap pertains to the rigidity of its lower leaf, for which, it is believed, ample provision was made. While conceding that the wooden construction of bear-traps will, at first, appeal strongly to many as preferable, because they can be built so that they will almost float; nevertheless, the all-metal construction yields advantages, especially in the superior stiffness of the structure, and in its adaptability to the abundant use of air, which must not be overlooked nor too lightly esteemed. Excessive weight and shortness of life are serious objections to common steel gates, but, with the development of materials which are less corrosive and have increased strength, as, for instance, nickel steel, weight may be materially reduced and durability greatly increased. To be sure, such material will also improve any other construction in proportion to its use therein, and its adoption in lock-gate construction seems to be indicated.

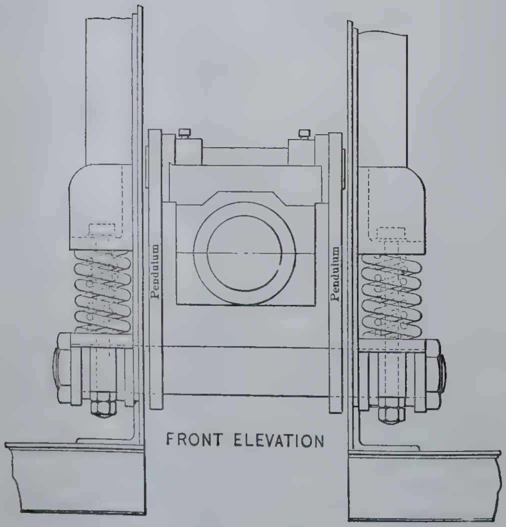
While the proper width of automatic weirs and the proportion

DETAILS OF PENDULUMS AND SPRINGS

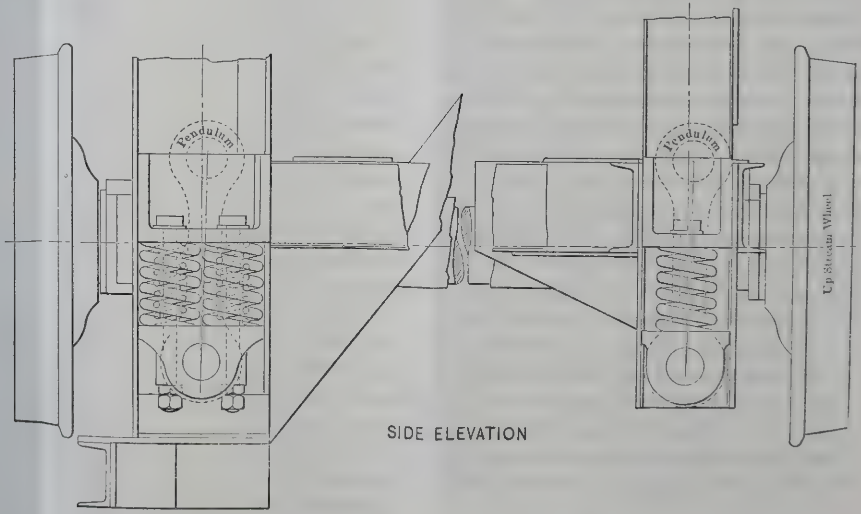
OHIO RIVER GATES



PLAN



FRONT ELEVATION



SIDE ELEVATION

of the total length of dam that should be devoted to them are in a measure dependent on many things, including particularly the special local conditions prevailing, yet, finally, these questions resolve themselves into the determination of what will most efficiently, safely and economically regulate the pool. Whatever will properly accommodate approaching rises will doubtless meet all other requirements satisfactorily. Having accepted this proposition, what proportion, then, of the entire length of dam should be devoted to automatic weirs, and what shall be their individual widths? Knowing the discharge of the river as it rises and the time necessary to lower the mechanical parts of the dam, the width of automatic weir necessary for the above could be approximately calculated. First of all, experience would indicate that at least one principal weir of liberal dimensions should be located at the end of the navigable pass opposite the lock, serving both as a drift-chute and a regulating weir. In order to secure a low sill for increase of discharge section, the bear-trap dam is well suited for this position. Since it is always easier to regulate the pool through excessive than through insufficient weir space, ample width should be provided; still, the width of the automatic part of this type is limited to the necessities of the case by the cost. Bear-trap weirs cost twice as much per linear foot as the Chanoine wicket dam. The size of the river is, of course, another factor.

The foregoing reflections on the principal regulating and drift-weir have been noted upon the presumption of the necessity for such weir under any circumstances, and in this respect it differs from the remaining weir structure, which must be governed to a greater extent by the special conditions in the case. The type of dam for that space will usually depend upon the total discharge section of the river as compared with its flood discharge. When the former is equal to or less than the average river section, a type of dam with a low sill should be adopted, and it is ordinarily wise to duplicate the principal weir. Where the discharge section of the river is excessive, the remaining dam space may be partly filled with a weir having shorter wickets, of the same type as the navigable pass, partly with a fixed dam or partly with a dam having a movable crest.

A very limited portion of Dam No. 1, Ohio River, is now automatic. The total width of the river, and consequently the length of the dam, is unusually great. In consequence of this condition, the structure closing the back channel between Davis Island and the left bank was originally a fixed dam. It being in need of radical repairs, and the advantage and necessity of increased automatic weir facility being apparent, there is now in course of construction a low fixed dam with a 5-ft. movable crest for its full length of 425 ft., less pier displacement. Where, therefore, the discharge section of the river will readily accommodate its high-water flow, any successful automatic movable crest yielding a vertical height approximately one-half that of the pass, will furnish valuable assistance as a pool regulator, and in addition will at moderate open-river stages effect by contraction an increased navigable depth of water on the pass-sill.

In the United States, there has been no actual practice, as far as known, with a type of dam with a movable crest.

Method of Operating Dam No. 1, Ohio River.—The Ohio River is subject to quick rises, which, in the winter, bring with them large quantities of both drift and ice. The knowledge of this resulted in the plan of maneuvering the navigable pass (Chanoine type) by the use of a boat, operated by working from above the dam, both in raising and lowering. (See Fig. 2, Plate XXI, a maneuvering boat in operation.)

As already stated, the attempt to use a service bridge on the three weirs proved unsuccessful, such bridge being taken out in less than two years by the drift and ice, in the case of two of the weirs. This dam has been in operation about seventeen years, and the result of the experience during that time is that it is impracticable either to raise or lower the navigable pass by the usual methods when ice of material thickness is running. The difficulty in lowering it was fully demonstrated in December, 1903, under the most favorable conditions, namely, a low and very slowly rising river and very thin ice running. Under these conditions ice gorged against the dam, and to the bottom of the river, nearly capsizing the boat, illustrating fully that under conditions of much ice it would be impossible to do anything with a maneuvering boat from above the dam. In raising and lowering the dam, the maneuver boat lies alongside the standing part. By means of spuds its points of contact with the dam are at or below the top of the horses. The draft of the water through the space between the wickets draws the ice under

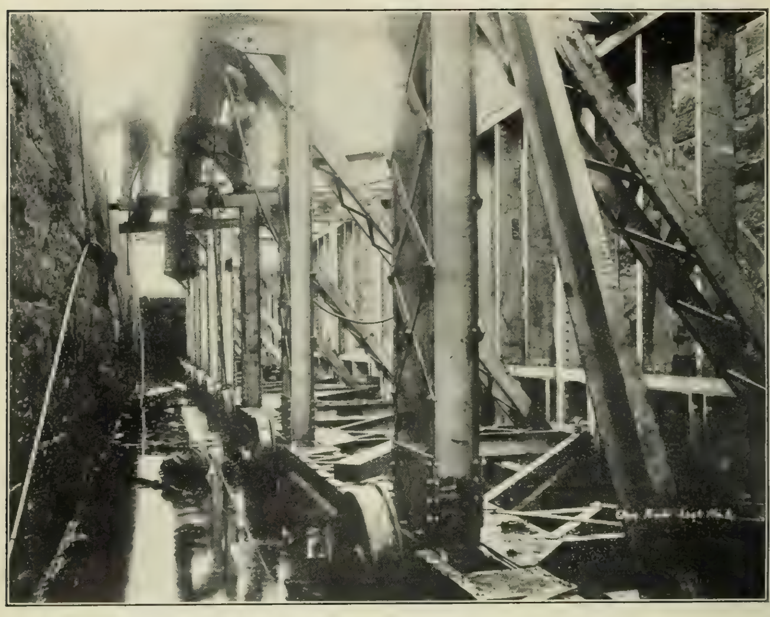


FIG. 1.—OHIO RIVER LOCK GATE.

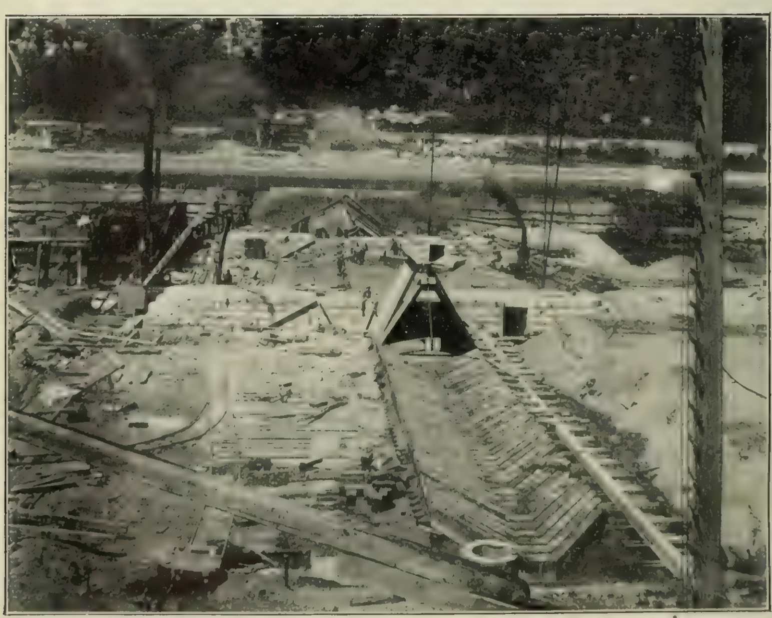


FIG. 2.—THE THOMAS A-FRAME DAM.

the boat and against the dam until it grounds and practically supports the boat. In several instances rises bringing with them floating ice have come so quickly that it was impracticable to lower the dam by the usual methods, and the wickets were lowered by a steamboat and barge, working from below, with the result that much damage was done to the structure. Having been forced by the drift and ice to abandon all types of dam with skeleton parts, or, practically, to accept the Chanoine type in the Upper Ohio, the result of operating this type for many years demonstrates its impracticability, with present appliances, in such a stream, generally from December until May, and that during that time navigation must depend upon the open-river depths. If some plan could be devised for lowering the dam, either by tripping bars, by a boat working from below, or by an overhead cable, it could be safely raised during the winter months at such times as the running ice would permit, and could be left up safely for extended periods.

The physical characteristics of the Ohio change gradually from source to mouth. Automatic weirs for pool regulation become less of a necessity as one proceeds down stream and service bridges, both for weir and pass, become practicable. The Chanoine dam alone, as the principal part, seems to be indicated in the upper reaches, while other types would probably be effective in the lower reaches. About the only modification of consequence noted in the Chanoine wicket is in the hurter. This modification was to widen the tail of the Pasqueau hurter from 4 to 24 in., and to place it flush with the apron. (See Fig. 24.) Raising the wickets has been much facilitated by this change.

Foundations for Locks and Movable Dam.—An idea seems to have been prevalent to some extent a few years ago to the effect that, since a movable dam is down when the river reaches its higher stages, there would be no movement of the river bottom beyond that ordinarily expected in the open, untrammeled river, and, consequently, foundations, if below the limit of ordinary scour in the river in its natural condition, would be safe without any further protection. The operation of such dams, however, soon proved the fallacy of this assumption. When a portion of a dam is first lowered, the river bed below, and along the outside of the lock walls especially, is subjected to currents as destructive as ever exist with a fixed-dam system, and has shown that the same precautions must be taken in the foundations for dams and locks in a movable-dam system as have been found necessary in a fixed-dam system. The great length of modern lock walls and the necessity of protecting with extreme care all that part of their foundation below the dam, have demonstrated more and more the advantage of a rock foundation for the lock itself. The foundations of locks, whether with fixed or movable dams, should be able to withstand the flow of water through the chamber in case the gate be suddenly broken. Experience within the last ten years and prior to that time has amply demonstrated the stability of dams founded on gravel, provided a sufficient apron is constructed below the same, and the dam itself made water tight at its upper face. Some sections of dams recently proposed or built are shown on Plate XXIII.

Ohio River Lock Gates.—The lock gates at present in use on the Ohio River are simply barriers a little longer than the lock is wide. They are pulled back and forth on a track across the chamber. A gate is composed of two parts: the trucks and superstructure. The trucks consist essentially of flanged wheels and journal boxes. In the journal box is arranged a saddle pin which carries one end of a pendulum link, the other end of which is attached to and carries the gate superstructure, which latter rests on springs above the journal. By means of this pendulum link the gate is free to oscillate laterally about 2 in. When there is no pressure on the gate the pendulum hangs vertical; when water pressure is applied, the gate is pushed down stream about 2 in. against the sill. When the pressure is released it assumes its normal position, thus eliminating all friction between the seats. This mechanism is working very satisfactorily. The plan of the gate is shown by Plate XXIV and Fig. 1, Plate XXV.

New Types of Movable Dams.—As far as the writer knows, the only essentially new type of movable dam actually built in the last ten years is a trestle dam, generally known as the "Thomas **A**-Frame Dam,"* Fig. 2, Plate XXV. A section of this dam, 120 ft. was built as an experiment in Dam No. 6, Ohio River. This dam was placed in service on August 17th, 1904, but the experience with the **A**-frame part has not yet been sufficient to enable one to make a fair criticism of its operation or express an opinion as to its merits.

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* *Transactions*, Am. Soc. C. E., Vol. XXXIX, p. 431.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON
ARTIFICIAL WATERWAYS.

By Messrs. E. L. Corthell, L. A. Huergo, D. and C. Stevenson
and B. F. Thomas.

E. L. Corthell, M. Am. Soc. C. E., New York City.—The speaker has had several opportunities to examine the Manchester Ship Canal, both during construction and since it has been in operation, and has kept himself well informed with regard to the development of its commerce. He has noted on each occasion the increase of facilities and the demand for more. From these indications, and from the conditions of population and industry stated by Mr. Hunter, he has never doubted the ultimate commercial success of the Manchester Ship Canal, and believes that the time will come when those who have invested in it will have a financial return. No commercial work of this kind that continually finds difficulty in keeping pace with the demand for facilities ever fails of ultimate financial success. Mr. Corthell.

L. A. Huergo, Esq., Buenos Aires, Argentine Republic.—The speaker congratulates Mr. Hunter, not only on the success of the Manchester Ship Canal, which, after all, is really an inland harbour and which will eventually be a paying investment to the shareholders, but also for giving so much of his valuable time to promote, in such an able way, before the profession at large, the interesting question of the struggle for and development of inland navigation of England. Mr. Huergo.

Whoever has followed the commercial development of Europe to any extent must be aware that, for some years past, England has

Mr. Huergo. not kept pace with the increasing industrial trade of the Continental nations and the United States. To a great extent, this is accounted for by the high cost of inland transport, aggravated by the actual conditions for shipping in some of the principal harbours of the island. The "danger of losing part of its existing trade" was admitted in 1902, in the case of the Port of London, by the Royal Commissioners appointed to inquire into its administration "by reason of the river channels and docks being inadequate to meet the increased and increasing requirements of modern commerce."

The case, mentioned by Mr. Hunter, of the pottery sent from Tunstall to London is very suggestive, and is evidence of the very high cost of freight on the railways and canals connecting London with Liverpool, or on the products of the Midland Counties.

The speaker has had opportunity of confirming the fact that home-made goods are shipped from Belgium, Holland and Germany to London at half the freight they pay from the Midland Counties to London by railway. The Blue Book returns for 1901 shew also that foreign products, formerly distributed from English harbours to the Continent, such as tea, coffee, rice, palm oil, etc., were received in Continental ports and transshipped from those ports to London, Hull, Leith and other English ports to an amount of over £1 500 000.

England must not only improve her harbours to meet the requirements of modern commerce, but must also reduce the inland freights from the place of production to the harbour, in order to meet the requirements of abundant return freight for the same great vessels.

Natural or artificial waterways are of very little commercial benefit unless, by their section and depth, they are capable of carrying large boats, whether on the high seas or on inland waterways.

The Aire and Calder Canal, which allows the passage of barges carrying 800 and 900 tons, has reduced the cost of freight to 0.05 pence per ton per mile, whilst on the link canal at Birmingham, belonging to the London and North Western Railway Company, the freight is 1.5 pence per ton per mile.

In a few words, it may be said that large and deep artificial waterways represent the future great commercial wealth of England, whilst narrow and shallow waterways mean its future commercial ruin.

It has been fortunate for humanity that, in the old times, the relatively powerful nations recognised, as a principle, the neutrality of the high seas, and nothing has added to the prosperity of nations more than this untrammeled intercourse by water. In the same manner, the common ownership of inland roads of communication has facilitated the development of districts which private ownership would have stifled; and, considering the cheapness of transport by water, a still greater benefit would be conferred generally if all streams were absorbed by the State and developed and utilized as common highways. **Mr. Huergo.**

D. and C. Stevenson, Edinburgh, Scotland.* (By letter.)—Since the date of the paper laid by the writers before the Congress at Manchester in 1890, from which Mr. Hunter has taken his information, considerable progress has been made with the laying out of the scheme for a Forth and Clyde Ship Canal *via* Loch Lomond. The best route has been settled, a detailed survey made and a design prepared, but the details of it cannot be divulged at present. In the complete design, the size of the locks has been increased, the canal itself enlarged and the estimate considerably increased. In the paper referred to and in the discussion thereon, the superiority of the Loch Lomond route over the Yoker route was fully dealt with, and it is unnecessary to enter into that question again. The only remark the writers would make is that, in dealing with the length of the canals by the various routes, it is obviously necessary to measure the distance from the same point in the Forth to the same point in the Clyde, say from Bo'ness to Ardmore, and if this is done the two routes by Loch Lomond and by Yoker are practically the same length. The Clyde, it should also be kept in view, is at present only 18 ft. deep at low water between Yoker and Port Glasgow, and in drawing up a scheme for making a 30-ft. deep-water channel from sea to sea, the deepening of this part of the river must be taken in hand, though it is not contemplated or allowed for by Mr. Douglass nor by previous advocates of that route. Mr. Hunter's remarks as to the usefulness of this canal from a strategic point of view, in addition to its commercial advantages, entirely coincide with the views which the writers have, for many years, when occasion offered, impressed on the attention of the authorities and public generally. **Messrs. D. and C. Stevenson.**

B. F. Thomas, M. Am. Soc. C. E., Louisa, Ky. (By letter.)—On Jan. 1st, 1897, the lock and needle dam at Louisa, Ky., on the Big Sandy River, West Virginia and Kentucky, were placed in operation. This was the first of a proposed system of some twenty locks and movable dams designed to give slack-water navigation over about 200 miles of river, the shores and tributaries of which abound in bituminous and cannel coal, which, it is expected, will be developed, and utilize this outlet to market (in addition to two railroads, now just entering the territory). This dam is fully described in a paper† by the writer, and it is only necessary to give briefly its principal features and to state that it has given excellent satisfaction for seven years. The experience thus gained has sug- **Mr. Thomas.**

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* Engrs. to the Northern Light-House Commissioners.

† *Transactions*, Am. Soc. C. E., Vol. XXXIX.

Mr. Thomas. gested a number of modifications which seem desirable in others of the series, particularly as they have a considerable increase in height; and the purpose of this discussion is to describe two movable dams of this system comprising these modifications, now nearing completion, and which, it is expected, will be put in operation before the close of the season of 1904.

DAM NO. 3.

Description.—The Louisa Dam (No. 3 of the system, although the first built), above mentioned, consists of a navigation pass, 130 ft. in length, having needles standing 13 ft. above the sill, and a weir, 140 ft. long, with needles supporting 7 ft. of water above the sill, the two parts being separated by a masonry pier. The trestles supporting the needles were all spaced 4 ft. center to center, but alternate trestles have since been removed, so that they are now 8 ft. center to center. This arrangement was made in order to facilitate the passage of driftwood at times of lowering dam. The needles are removed by pulling up stream on a chain to which their tops are attached at intervals considerably greater than their distance from center to center, thus enabling one needle to be partly removed before its fellow is started, as it would not be possible, under full head, with the power at hand, to start several simultaneously, although, when the heads have been removed a few inches away from the supporting bar which connects the trestles, the pressure rapidly diminishes, and there is usually no difficulty in removing the whole number quickly. The supporting bars are hinged to the trestles at one end and, at the opposite end, are connected with the next trestle by an arrangement which can be unlatched by mechanism on the floor above. When great speed in lowering the dam is required, by reason of a sudden freshet, the ends of these bars can be released, and the needles will fall between the trestles and float up below, being secured by ropes in advance. This has given this bar the name of "escape-bar." After the removal of the needles, the trestles are lowered on the masonry by a continuous chain leading to a winch on the masonry, by which they are also raised when the dam is to be put in, the needles being placed from a small derrick-boat, one at a time. The lock is of masonry with wooden gates, and is filled through gate valves and emptied through wall valves of the butterfly type.

DAMS NOS. 1 AND 2.

General Description.—The two new dams are below Dam No. 3, No. 1 being 26 miles, and within 1 500 ft. of the junction of the Big Sandy River with the Ohio, and No. 2 being half way between

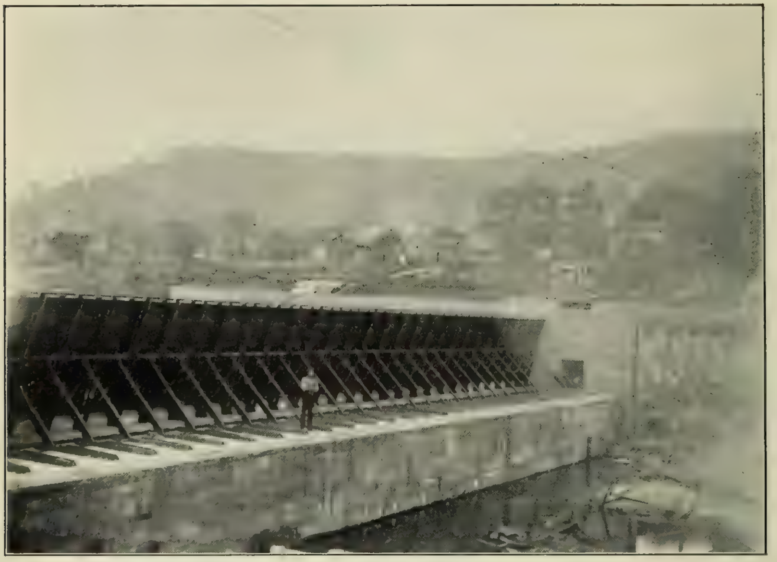

Fig. 1.—Down-Stream View of Wickets on Weir.

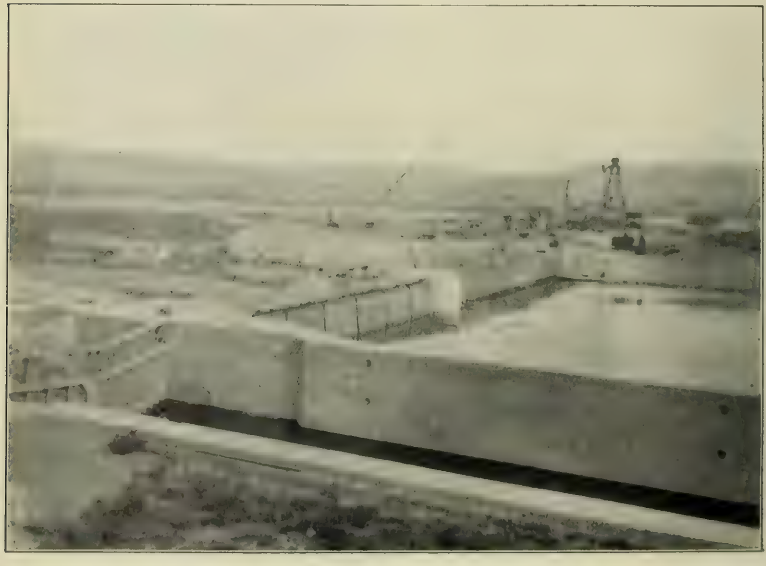

Fig. 2.—General View of Lock and Dam.

Mr. Thomas.

Nos. 1 and 3. The new dams are practically similar in construction, the lengths and heights of weirs being the only difference, the passes being identical. The locks are also similar except that the head sustained at No. 1 is considerably greater than that at No. 2, necessitating higher gates.

All the masonry is of Portland cement concrete, founded on bedrock at depths varying from 3 to 16 ft. below extreme low water.

The locks are 258 ft. over all, with a distance of 192 ft. between hollow quoins, and they have a clear width of 55 ft. The distance from miter sill to upper-pool level at No. 1 is 22.5 ft., and at No. 2, 18.5 ft., with lifts at normal pool below of 16 ft. and 12.5 ft., respectively. The gates are of structural steel, vertically framed with buckled plate sheathing. The locks are filled and emptied through culverts in the walls closed by cylindrical valves. All the maneuvers are performed by hand power.

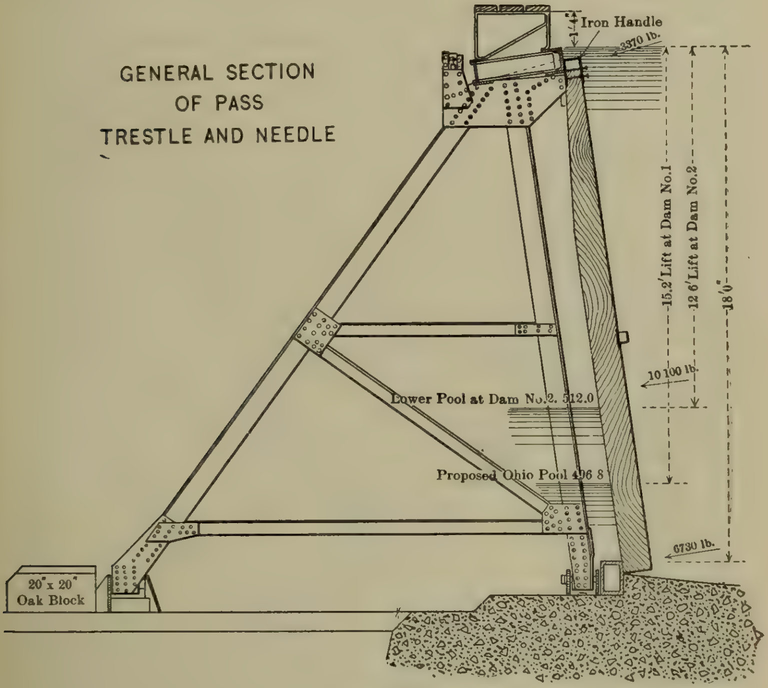

Fig. 25.

The dams consist of a navigable pass, 140 ft. in length, having a depth below upper pool of 18 ft. closed by trestles and needles; and a weir, 160 ft. long, with a depth on sill of 10.5 ft. at No. 1, and a

Mr. Thomas length of 136 ft. and depth on sill of 11.5 ft. at No. 2, closed by Chanoine wickets made of steel. The two sections are separated by a pier, 10 ft. in width.

Trestles.—The trestles are spaced 20 ft. between centers, and are connected by trussed girders, or escape-bars, which support the tops of the needles, the bottoms resting against a cast-iron sill anchored to the masonry. The girders are hinged to the heads of the trestles on the up-stream side by pins resting in an open slot, and are removed and stored on the maneuvering-boat when not in use. The trestles are hinged to journal boxes on the masonry and have no axles. The chain by which the trestles are raised and lowered is attached to each trestle before lowering by a latch, which is released when they are raised, allowing the chain to pass on through the trestle-head, supported on a sheave. The chain is drawn in or paid out by a winch in a recess on the outer lock-wall. The escape-bars have proper connections with the lock and pier masonry. The sill of the pass is at about low-water mark at No. 2, and somewhat above it at No. 1, where low-water mark varies considerably, owing to the deposit of sand in the Ohio River backwater. The sills of the weirs are 7.5 ft. and 6.5 ft. above those of the pass at Nos. 1 and 2, respectively.

Needles.—The needles are of long-leaf yellow pine, 12 by 12 in., tapering in the upper 5 ft. to 6 by 12 in. They have an iron band and handle at the head with rings near the center and bottom for convenient handling. Their weight is about 900 lb. when wet.

Wickets.—The wickets are of the Chanoine type, built of steel shapes and buckled plates, 3 ft. 9 in. wide, spaced 4 ft. center to center, thus leaving a space between of 3 in., which will be closed with needle or joint covers of wood during dry weather. These wickets differ from the Chanoine type in only one important particular. In that form, the framework rests against the sill at the bottom, thus making it impossible to shut off entirely leakage between the wickets immediately on the sill, because of the thickness of the framing. This has been modified so that the sheathing only rests against the sill, the framework being cut off just above. In this way, the thickness of the portion resting against the sill is reduced to ½ in., and it is possible to close the space more completely and stop leakage. Another modification worthy of mention is that chain-stops are made in the tops of the wickets to hold the chains of adjacent wickets; thus when the first wicket is raised, it brings up the chain of the second, and so on, so that it is not necessary to grapple for a hold before raising, as on the Ohio. On the Kanawha, these chains are attached to the service-bridge trestles, but there will be no bridge on these weirs, the raising being done from a derrick-boat, as is done on the Ohio River.

Mr. Thomas.

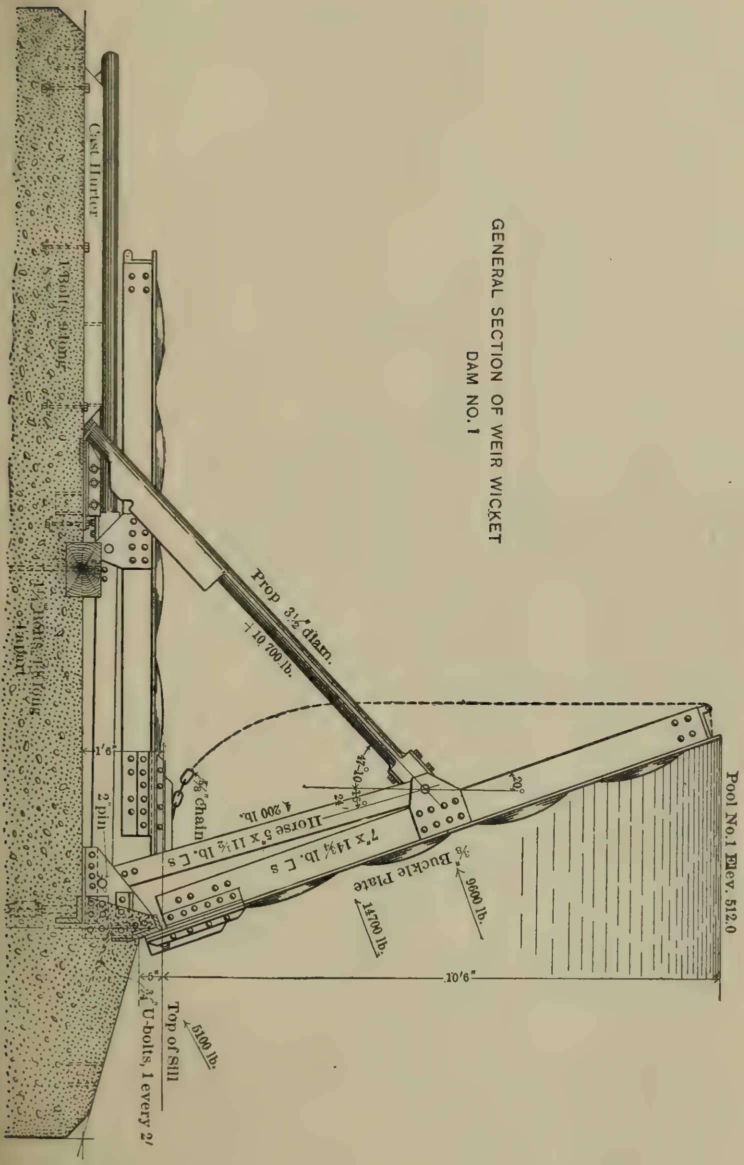

Fig. 26.

Mr. Thomas. *Tripping Bar.*—The wickets are lowered by a tripping bar placed on the masonry floor, and operated in two sections by hand machinery located in the pier and abutment. This bar has teeth at intervals which engage with the props of the wickets and pull them out of their seats in the hurters on the masonry floor. The bar has a section of 1½ by 5 in.

Maneuvers.—Such, in brief, are the chief features of these dams, and it only remains to describe the method of operation and point out what are believed to be the advantages over dams of similar character elsewhere, and make a suggestion or two looking to further improvement.

We will suppose the dam is up, and must be lowered in order to pass a freshet. First, the wickets next the abutment are thrown by means of the abutment section of the tripping bar. As these wickets sustain the full head of water in the pool, considerable power is required, and the lugs on the tripping bar are spaced so that, at first, only one wicket will be thrown at a time. This will continue till six are thrown, and thus open a space next the abutment, 24 ft. wide. The increased discharge through this space will begin to lower the pool above and fill the one below, so that the next wickets will be lowered under much less head (and consequently with less power), and the number thrown simultaneously can be doubled. The section of tripping bar next the abutment throws but nine of the wickets, the remainder being lowered by a similar bar operated from the pier. The spacing on this bar is such that four wickets can be thrown simultaneously, near the pier, it being believed that the head will have decreased sufficiently to permit this. Should this assumption prove incorrect, the wickets can be lowered with the maneuvering-boat, as is now done with all the wickets on the Ohio.

After the weir has been lowered, if sufficient area has not been provided for the passage of the rising water, it will be necessary to open the pass. First, the needles are connected by wire lines or chains run through the handles on the head, each bay having a separate line. These are attached to a hawser fastened to the lock, or to one of the trestles. Then the maneuvering-boat is located above the needles about 30 ft. from the pier, with stern toward the lock. The derrick is connected with the chain on the center of the down-stream side of the escape-bar, which is lifted up by the engine on the boat, revolving around its hinge pins in the sockets on the up-stream side of the trestle-head. The up-stream side of the escape-bar, against which the needles rest, is thus raised above the heads of the needles, and they fall, floating into the quiet water below the standing portion of the pass, and finally below the lock. The escape-bar is swung around to the boat, where it is stored away until

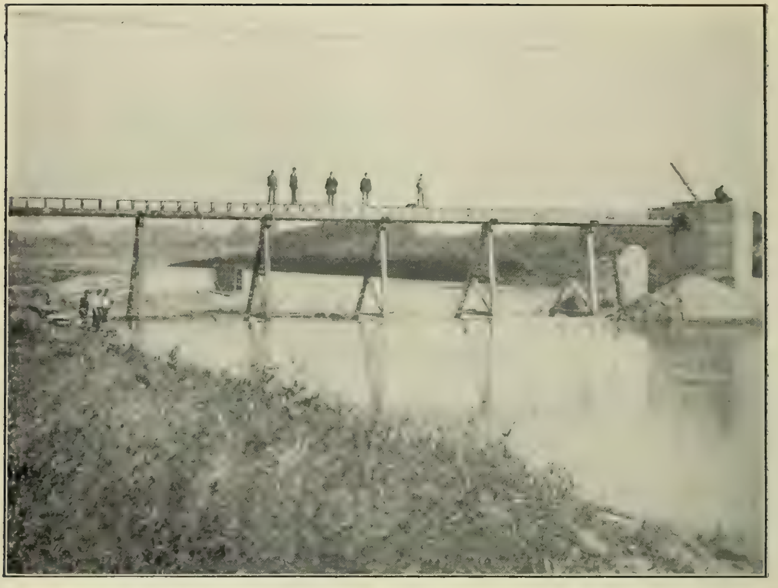

FIG. 1.—PASS TRESTLES FROM ABOVE, SHOWING ESCAPE-BARS AND WALKWAY.

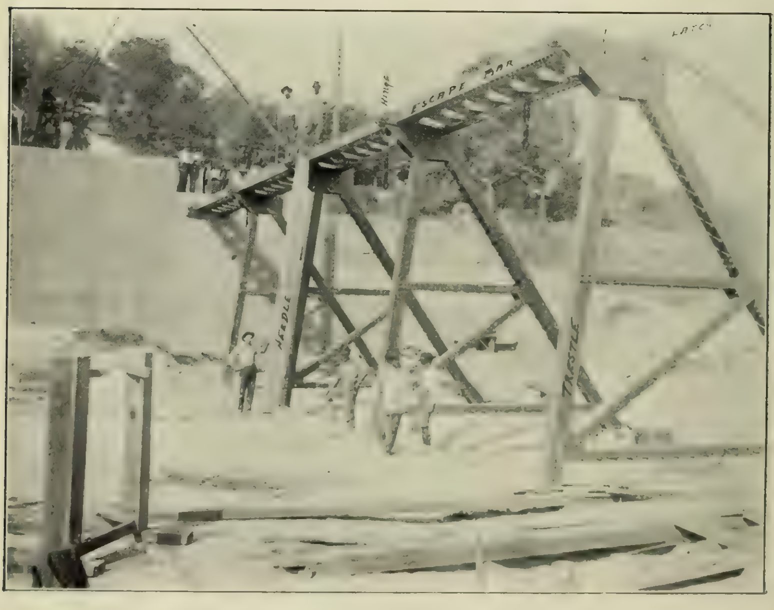

FIG. 2.—PASS TRESTLES, ESCAPE-BARS AND ONE NEEDLE.

needed again. The boat is then moved back about 20 ft. toward the lock, and the operation above described is repeated, releasing the second bay of needles. This leaves a trestle standing in the current without protection from drift, in case any is running, and the trestle will be lowered by paying out the chain on the winch at the lock-wall, its movement being governed by a friction brake. This trestle would not start down of its own accord (or rather it would start toward the lock-wall instead of toward the pier, by reason of the weight of the chain), and a chain is attached to it which passes over a sheave into a well in the pier where a weight is connected to it, which starts it downward as soon as the hoisting chain is slackened. In lowering the trestle is not allowed to reach quite to the floor, at first, the hoisting chain being attached, by a suitable latch, to the head of the next trestle. After the next escape-bar has been removed, the weight of the first trestle, partially lowered, will start the second trestle downward as soon as it is released at the winch. A repetition of these operations will, in a few minutes, lower the entire pass, leaving the needles afloat, and the trestles lying out of danger on the masonry below the sill, and the boat lying alongside the lock-wall above the dam. There is one needle above each trestle (six in all) which does not escape, and these are cared for, with the escape-bars, on the boat. It is the intention to make these very light (mere planks), and support them against the up-stream posts of the trestles at proper intervals. **Mr. Thomas.**

To raise the dam, the pass trestles are first brought up with the winch, or with the boat, the chain latches being released as each trestle comes to the vertical and the escape bars placed in position. The needles are then lifted by the derrick, one by one, out of the water and placed against the sill and escape-bar. It is desirable to perform this operation as rapidly as possible, so that too much head will not accumulate, as it is not easy to place large needles in a swift current, and it is not always possible to secure joints as tight as desired. There is a tendency in the last needle put in to travel away from its fellow, caused by the current developed along the line of the dam and around the last needle placed. When the head is as much as 2 or 3 ft., it is sometimes necessary to "break the space up" by placing the needles a foot or so apart, filling in later with other needles, and then drawing them all close together by means of power from the boat, closing the final space with a joint cover resting on two needles a few inches apart.

After the pass has been put in, the water will rise and flow over the weir. This will be raised, wicket by wicket, with the maneuvering-boat, beginning at the pier, the boat lying against the needles at first, and later against the raised wickets, or anchored above. When nearing the abutment, where wickets may be raised against

Mr. Thomas. full head of pool, or more, the boat can be tied to shore check-posts, put in for that purpose, thus relieving the standing wickets of unnecessary strain. The pier and abutment masonry has been extended up stream and brought nearly to weir level with a view to placing a service bridge for weir maneuvers later on, in case it is found that operating from a boat is unsatisfactory.

Modifications.—The principal modifications in the pass are in spacing the trestles 20 ft. instead of 4 ft., and the substitution of a girder, revolving vertically, for the escape-bar having a horizontal movement. The wide spacing will prevent drift from lodging (or, if it does lodge, the trestles are so heavy that no damage will be done to them), reduces the number to be operated from 34 to 6, and decreases the total quantity of iron work required more than 25 per cent.

The time required for raising or lowering the trestles, with the decreased number, will be about one-fifth that necessary with closely spaced passes.

With the exception of the modification noted above for reducing leakage, the wickets follow practically the Chanoine model. The tripping bar, while used with satisfactory results on all wicket dams except one in France and Belgium, has not found favor in the United States, owing, probably, to the failure of those tried on the Kanawha. This failure was due largely to the lightness of the bars and the arrangements for controlling their movement, rather than to any defect in the system itself. One of the main advantages of a tripping bar is that the wickets can be lowered in the ice, because they do not have to be pulled up stream before the prop is released, as is the case with the dams on the Ohio and Kanawha.

Advantages.—The first requisite of a dam for the Big Sandy River is tightness. The low-water discharge sometimes is less than 100 cu. ft. per sec., and it has been as low as 48 cu. ft. The needle dam is absolutely water-tight, when care is exercised in placing the needles. It thus serves the purpose admirably in this particular. The wicket weir may not prove perfectly tight, as it is difficult to shut off all leakage near the sill, but this has been, it is believed, reduced to the minimum possible with a dam of this type, and, by carefully placing the joint covers between the wickets during the dry season, it is hoped that the pools can be maintained to a fair degree.

The second matter of importance in a dam for a torrential stream is the ability to lower, in part or as a whole, with great rapidity, in case a sudden rise comes unheralded. Such freshets sometimes rise 2 ft. per hour, and 1 ft. per hour is not uncommon. When it is known that these floods may reach a height of 40 or even 50 ft. above low water, the necessity for speedy action will be apparent. The ability to "escape" a 20-ft. bay of needles instantly and to follow it by another and another, as rapidly as navigation above and below will admit, will be a great comfort to those who have had to pull against the stream and fight driftwood and saw-logs away from frail trestle-work. Mr. Thomas.

Future Improvements.—The writer will suggest in future dams for this river and for those of similar nature the substitution of a cableway for the maneuvering-boat, placing the same over the proposed line of dam upon beginning work so that it may be used in the transfer of materials at the outset, and later on in the construction of part or all of the lock and the whole of the dam, and finally in its operation. It is as practicable to raise the trestles and place the needles and to remove the needles and lower the trestles again with a cableway as with a boat, and there will be no boat to care for during ice and freshets. With such good power located immediately over the weir, Thenard shutters can be substituted for Chanoine wickets, and a thoroughly tight weir can thus be secured without resort to joint covers. Where there is sufficient power at hand for raising against a full head, there is no doubt of the superiority of the Thenard over the Chanoine dam. The successful use of the former on Indian weirs for a very long period has proven its reliability beyond question. The difficulty of applying sufficient power to raise it under full head has alone prevented its wide application on weirs of movable dams in this country, and it is believed that the cableway, now in such general use on works of construction, will solve this problem of operation as well as several others.

It seems a great step from trestles spaced 4 ft. apart to those spaced 20 ft. apart, as described above, but if a cableway is introduced for handling the girder connecting them, there will be no reason why the spacing cannot be increased still further. The girder in the present dams weighs approximately 1¼ tons; its weight may be more than doubled if handled by cableway.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

UNDERGROUND RAILWAYS.

Congress Paper No. 88.

THE METROPOLITAN SYSTEM OF PARIS.

By L. Biette, Ingénieur des Ponts et Chaussées; Ingénieur en
Chef des Travaux de Paris adjoint à l'Ingénieur en Chef,
Chef du Service Technique du Metropolitain
municipal, Paris, France.

Congress Paper No. 89.

UNDERGROUND RAILWAYS IN GREAT BRITAIN.

By Basil Mott and David Hay, Members, Inst. C. E.,

Congress Paper No. 90.

UNDERGROUND RAILWAYS IN THE UNITED STATES.

By William Barclay Parsons, M. Am. Soc. C. E.,
New York City, U. S. A.

Discussion of the Subject by

Robert Moore, St. Louis, Mo., U. S. A.
Samuel B. Fisher, St. Louis, Mo., U. S. A.
Moritz Wormser, New York City, U. S. A.

E. E. R. Tratman, Chicago, Ill., U. S. A.
W. M. Camp, Chicago, Ill., U. S. A.
George A. Kimball, Boston, Mass., U. S. A.
George W. Parsons, Steelton, Pa., U. S. A.
Wilkie Woodard, Cincinnati, Ohio, U. S. A.
Howard A. Carson, Boston, Mass., U. S. A.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

Paper No. 88.

UNDERGROUND RAILWAYS.

THE METROPOLITAN SYSTEM OF PARIS.

By L. Biette.*

Translated from the French.

Up to the present time Paris has been the only city in France in which the idea of handling passenger traffic by underground railways has received practical application.

For a number of years, Paris has had a Belt Line, a steam railroad, passing around the city close to the fortifications. Although this railroad carries passengers and facilitates access to the suburbs, its principal function is the exchange of freight between trunk lines centering in Paris, and it cannot be classed as an interurban railway.

During the last few years new lines of underground railways have been constructed in Paris; the Compagnie de l'Ouest has extended one of its suburban lines along the left bank of the Seine, as far as the Invalides; the Compagnie d'Orléans whose terminus was formerly the Austerlitz Station, has brought its trunk line as far as the Quai d'Orsay; and the City of Paris has undertaken the construction of a system of electric railways called the "Chemin de fer Metropolitain."

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*Ingénieur des Ponts et Chaussées; Ingénieur en Chef des Travaux de Paris adjoint à l'Ingénieur en Chef, Chef du Service Technique du Métropolitain municipal.

The extensions constructed by the Ouest and Orleans Railroads for general railroad traffic cannot be considered exactly as urban railways, although they have stations opened to local traffic. Their principal, and, in fact their only practical purpose, is to bring the arriving and departing passengers and merchandise from the suburbs or the Departments nearer the center of the city. The Metropolitan Railway, on the contrary, built for local traffic, is used only for handling urban traffic. Built for the purpose of relieving the lack of public transportation facilities in Paris itself, of developing poorly populated and distant suburbs having no connection whatever with trunk lines of railroads, it constitutes a complete and comprehensive system answering precisely to the term "underground railways" as applied in the United States. Consequently, the Metropolitan Railway of Paris only will be considered in this paper.

* * *

A law of March 30th, 1898, declared that on account of local interests it would be for the general good of Paris to establish a Metropolitan Electric Railway System for the transportation of passengers, and that the following six lines should be constructed:

1.—A line from the Porte Vincennes to the Porte Dauphine;
2.—A circular line following the old outside boulevards;
3.—A line from the Porte Maillot to Ménilmontant;
4.—A line from the Porte de Clignancourt to the Porte d'Orléans;
5.—A line from the Boulevard de Strasbourg to the Austerlitz Bridge;
6.—A line from the Cours de Vincennes to the Place d'Italie.

Besides, an agreement attached to the above-mentioned law provides for an eventual franchise covering the following two lines:

7.—From the Palais Royal to the Place du Danube;
8.—From Auteuil to the Opera through Grenelle.

This eventual franchise which declared these last two lines to be necessary for the public welfare, was granted finally by two subsequent laws dated April 22d, 1902, and April 6th, 1903.

In this paper it is not the writer's intention to include a detailed analysis of the conditions specified in the franchise for the Municipal Metropolitan Railway of Paris, and only the fundamental points which regulate the franchise will be summarized.

The road is to be double-tracked with a standard gauge of 1.44 m.; the width of the cars is to be 2.40 m.; a clearance of 0.50 m. is to be provided between passing cars, and a clearance of 0.70 m. is required between cars and side walls, or parapets, at a height of at least 2 m. above the rails.

The franchise was granted to the Compagnie Générale de Traction for a period of thirty-five years. This company was reorganized as a corporation whose only purpose should be the operation of the Metropolitan Railway, and by a State decree of April 19th, 1899, was called the "Compagnie du Chemin de fer Metropolitain de Paris."

The City of Paris takes charge of all structural work, that is all tunneling, excavations and viaducts necessary to complete the roadbed and to restore the streets utilized for the work to their former condition. In addition to this the city must construct the passenger platforms in the stations, but not the passageways giving access to them.

All other expense, such as constructing tracks and electric transmission lines, plants and power stations, as well as purchasing the necessary sites, providing the stairways or elevators for the stations, and the rolling-stock, etc., are maintained by the company to whom the franchise was granted.

The rates are 0.15 franc for a second-class and 0.25 franc for a first-class ticket from one point on the railway to another.

A part of the gross earnings belongs to the City of Paris at the ratio of 0.05 franc for each second-class and 0.10 franc for each first-class ticket; this amount will increase by 0.001 franc for each 10 000 000 passengers till it reaches 0.055 and 0.105 franc, respectively, per ticket, in proportion as the number of passengers increases at the same ratio from 140 000 000 to 190 000 000 per year.

* * *

The eight lines recognized as necessary for public welfare have a total length of about 77 km., exclusive of the spurs connecting them, and form three distinct systems. The first three lines form a system 42 km. long, the next three form a second system 20.7 km. long and the last two, a third system 14.5 km. in length. The first system must be completed in eight years at the most, this limit expiring March 30th, 1906; the second and third systems must be completed ten years later. Consequently the entire Metropolitan System must be completed by March 30th, 1916, at the latest, and it is now certain that this time will be considerably shortened.

The Metropolitan will be elevated for 10.45% of the total length of the Circular Line and the line from the Cours Vincennes to the Place d'Italie. All other lines will be underground. The maximum grade will be 0.04 m. The normal minimum curve will have a radius of 75 m. decreased occasionally to 50 m., but to as great an extent as possible the radius will be at least 100 m.

In order to meet the expenses of constructing the Metropolitan System, the City of Paris has been authorized by two laws, one dated April 4th, 1898, the other, June 26th, 1903, to contract special loans amounting to 335 000 000 francs. The portion of the gross receipts of the system belonging to the city is to be set aside to repay these loans.

Of these 335 000 000 francs, only 285 000 000 are necessary to cover the expense of constructing the tunnel; the balance will be applied as follows: to the borrowing expenses, 7 000 000 francs; to the expenditure occasioned by tearing up the streets at certain points, 28 000 000 francs, and finally, to provide a reserve, 15 000 000 francs, which, later on, may be spent in constructing branch lines or spurs.

It has already been mentioned that the total length of the eight lines composing the system was 77 km., but this is measured by adding only the length of each line measured on its axis. If the side tracks, crossings, etc., are added, the total length will be 84.7 km. counting the single track for only half its actual length. Taking this figure as a basis, it will be seen that the construction of the structural part of the Municipal Metropolitan Railway will cost the city at an average of 3 400 000 francs per km. The other expenses, supported by the company having the franchise, may be estimated at 1 500 000 francs per km., so that the whole cost per kilometer of double track may be taken as 4 900 000 francs.

* * *

According to the terms of the franchise annexed to the law of March 30th, 1898, the construction of the first three lines only was made compulsory for the City of Paris, but the success following the opening of the first line was so great that it was decided to undertake the construction of the entire system.

After a careful study of the connections to be provided for between the different lines, and of the best operating conditions, the plan of the system has been slightly modified. Line No. 1 goes directly from the Porte Vincennes to the Porte Maillot. The second line, following the circular line of the old outside boulevards, has been cut in two portions: to the northern part following the boulevards on the right bank of the Seine has been added the branch, Porte Dauphine—Place de l'Etoile, so that the northern Circular Line follows a continuous line along the northern boulevards from the Porte Dauphine to the Place de la Nation. The southern section starts from the Place d'Italie, the branch coming from the Place de l'Etoile has been connected to Line No. 6 so as to form a continuous line from the Place de l'Etoile to the Place de la Nation along the southern boulevards; at the same time, the new branch starting from the Place d'Italie has been connected with Line No. 5 and this last line has been extended to the Gare du Nord, so as to have a continuous line from the Gare du Nord to the Place d'Italie. The starting point of Line No. 3 has been changed to the crossing of the Boulevard de Courcelles by the Avenue de Villiers at the point of separation with the northern Circular Line. Finally, the plan of Line No. 4 has been deviated in its central part so as to come into the city.

The order in which the different lines are to be constructed was determined by the convention granting the franchise, but the City of Paris is allowed to construct more than one line at a time provided the general order of construction is not changed. Advantage has been taken of this privilege.

During the latter part of 1898 work was begun on the Metropolitan Railway simultaneously on Line No. 1 from the Porte de Vincennes to the Porte Maillot, on the branch of the northern Circular Line, No. 2, going from the Porte Dauphine to the Place de l'Etoile, and on the section of the southern Circular Line No. 2, between the Place de l'Etoile and the Place du Trocadero. This part of the system was completed in 1900.

The situation is now as follows (Plate XXVIII): Line No. 1 from the Porte de Vincennes to the Porte Maillot, the northern Circular Line, No. 2, from the Porte Dauphine to the Place de la Nation along the boulevards on the right bank of the Seine, and the section of the southern Circular Line, No. 2, between the Place de l'Etoile and the Seine, are in operation. The southern Circular Line, No. 2, from the Seine to the Place d'Italie along the boulevards on the left bank of the Seine is completed as far as the tunnel is concerned, and it is only necessary to finish the great works at the two crossings of the Seine in order to connect it with the lines in operation. These works are now under way and will be ready sometime in 1905. Line No. 3 is nearly completed and will be opened to traffic at the end of 1904. Finally work has been commenced on Lines Nos. 4, 5 and 6, and the preliminary plans for the construction of Lines Nos. 7 and 8 are under way.

The lines opened to traffic have been successful beyond all expectations. For instance, if Line No. 1 from the Porte de Vincennes to the Porte Maillot is considered, it will be found that the number of passengers carried, no matter to what distance, was:

52 096 285 in 1901;
63 021 068 in 1902;
67 993 147 in 1903.

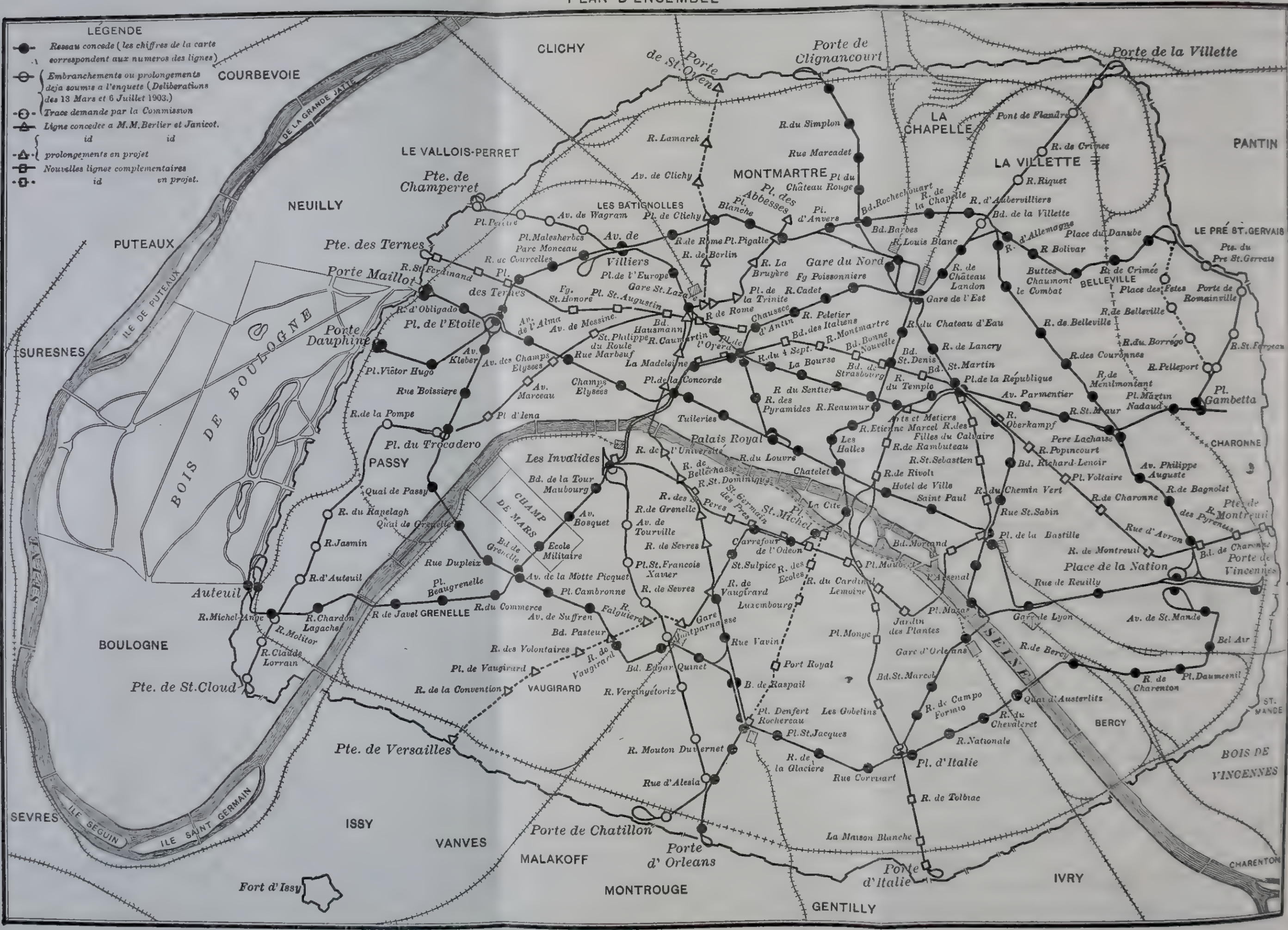
The number of passengers reported per kilometer for this same line of 10 576.31 km. was: 4 925 752 in 1901; 5 958 700 in 1902, and 6 428 816 in 1903. This increase in traffic is greater than any increase obtained elsewhere to date.

This favorable situation has caused the City of Paris to contemplate the construction of new Metropolitan lines in order to complete the system. During 1903, a franchise was granted to MM. Berlier and Janicot for a line starting at Montmartre (Place des Abbesses) and going to the Montparnasse Station by the following route: Trinité, St. Lazare Station, Place de la Concorde, Boulevard St. Germain, Boulevard Raspail and Rue de Rennes, with future extensions to the Porte de St. Ouen on the north and the Porte de Versailles on the south. At the same time inquiry as to the public utility of adding five new branches or extensions to the existing lines has been started. These branches are to be as follows:

Connection between Lines Nos. 3 and 7 from the Place Gambetta to the Place du Danube;
Extension of Line No. 7 toward the Porte de la Villette;
Extension of Line No. 3 toward the Porte de Champerret;
Branch of the southern Circular Line, No. 2, from the Place du Trocadero to the Porte de St. Cloud;

LIGNES METROPOLITAINES (Mars 1904)

PLAN D'ENSEMBLE



Branch of Line No. 8, from the Invalides to the Porte de Chatillon.

Finally the Municipal Board of the City of Paris has decided to commence an inquiry as to the following lines:

Line from the Porte d'Italie to the Porte de Montreuil, through the city and the Place de la Republique;

Line from the Opera to the Place des Ternes along the Boulevard Haussmann and the Avenue des Ternes;

Line from the Trocadero to the Place St. Augustin; extension to the branch of the southern Circular Line, No. 2, from the Trocadero to the Porte de St. Cloud;

Circular Line called "inside ring," from the Invalides back to the Invalides through the Grand Boulevards on the right bank of the Seine and the Boulevard St. Germain.

The Municipal Board has asked also that inquiries concerning other lines, too numerous to be mentioned here, be started.

After adding the new lines enumerated above, the grand total length of the Metropolitan System will have been increased from 77 to 134.2 km.

It remains now to state how this great work has been conceived, to give some details of the methods adopted to accomplish it and briefly some information about the most remarkable works which it has been necessary to undertake at difficult places on the lines already in operation or under construction.

* * *

Inspired by the example of London, it was in 1872 that the first idea of a metropolitan railway in Paris began to take form. The English capital had a metropolitan railway similar to the Parisian Belt Line except that it passed through more thickly populated districts than that in Paris. Later on, London began the construction of a series of underground electric railways called "tube railways," the oldest being the City and South London, the latest, the Central London, whose system is now being extended. Among the innumerable schemes, emanating from officials or private individuals, proposed before actual work began on the Metropolitan System of Paris, one, similar to the method used in constructing the London tubes, attained some notoriety. As is known these railways are constructed in circular tunnels with metallic casings formed of cast-iron segments bolted together. The two tracks are laid in separate tunnels with a cross-section as similar as possible to the section of the rolling-stock. These tunnels are constructed at a great depth. A wider section is adopted for stations which can be reached only by elevators running in vertical wells with metallic casings. This construction is an excellent solution when the tunnel has to be built in wet ground, across the bed of a river for instance, and it was really for this reason that it was used first in London. In such ground, indeed, the only way to dig is with a compressed-air shield, and the circular form is the only one well adapted to the use of this device. The collecting sewer of Clichy, with an elliptical cross-section, constructed recently in Paris, by a shield, without compressed air, has given a great deal of trouble on account of the instability of the device which it was found very hard to keep in its normal position. On the other hand, it is logical to separate the two tracks and place them in two tunnels, because, while it is possible, as at Blackwall, to cross the bed of the Thames with a single shield of large size, it is easier, safer and cheaper to use the smaller size. Finally the cast-iron casing is justified here by the necessity for a very strong wall easily and rapidly constructed without cumbersome installations in a small compass. But if the ground to be tunneled is not wet and is sufficiently cohesive, as is generally the case in London, this construction is hardly justified. The cast-iron casing is entirely unnecessary; its cost is a dead loss on the original capital and amounts to a great deal on an extensive system. The two tunnels, in which tracks and stations are separated, give constant trouble in operating. The great depth of these tunnels makes access to them difficult, causing loss of time for the public and heavy operating expense for the company, owing to the necessity of constantly using elevators. The great depth may cause serious trouble to adjacent buildings, either by accidents during construction, or by the operation of the road, by reason of the propagation, through the encompassing ground, of the shocks and vibrations caused by trains.

All these disadvantages, shown by the example of the London tubes, no doubt would have happened in Paris, increased by the fact that the Parisian subsoil was wet at a number of points on account of more or less important subterranean sheets of water, if the same system had been adopted, and the work at a great depth would have been more difficult, more dangerous and more costly owing to the necessity of frequent recourse to the use of compressed air.

On that account the engineers in charge of the survey of the Parisian Metropolitan System, have adopted an entirely different plan which may be defined by the following characteristics: absolutely no metallic tubings, except in crossing the bed of the Seine; adoption of a double-tracked masonry tunnel; this tunnel to run as near the surface as possible.

The advantages of this plan are exactly the opposite of the disadvantages recounted above: doing away with the metallic casings effects a very important economy in construction; the adoption of a single double-tracked tunnel facilitates operation; the track, being near the surface, affords easier access to the stations, lessens the inconvenience and expense caused by the use of elevators, and the danger to adjacent buildings during construction and inconvenience during operation.

Objections to the surface plan adopted at Paris may be raised on the ground that it requires altering underground conduits: sewers, water and gas mains, electric cables, etc., which are very numerous in the subsoil of the metropolitan highways. This objection cannot be denied, but it has always been possible to replace these conduits without serious trouble, and the expense incurred, although very heavy, is nothing compared to the increase in cost which the tube would have caused to no purpose; this cost, in any case, has no weight if the advantages of the adopted plan are considered.

It appears necessary to give here a summary description of the cross-sections used in the construction of the Metropolitan Railway, and also some information regarding the materials used in the construction.

The standard section of the double-tracked subway, Plate XXIX, is formed by an elliptical arch having a width of 7.10 m. and a rise of 2.07 m. supported by two side walls, 2.91 m. high, finished inside by circular arcs; the section is completed by an invert having a rise of 0.22 m. The total inside height of the tunnel, consequently, is 5.20 m.; the rail is 4.50 m. from the intrados at the keystone, and

0.70 m. above the bottom of the invert. The width at the rail level is 6.60 m. The thickness of the arch at the keystone is 0.55 m., the side walls, 0.75 m. and the invert, limited below by a horizontal surface, is 0.50 m. thick at the center.

The construction of this cross-section is possible only where the distance between the rail and the surface of the ground is not much less than 6 m. When it has not been possible to comply with this condition, a metallic roof, supported by masonry walls, has been built, so that there always will be a minimum clearance of 3.50 m. above the rails.

The parts of the tunnels connecting the different lines are built with single track. The arch roof is 4.30 m. wide and rests on side walls 2.62 m. high; the surface of the floor is slightly curved with a rise of 0.075 m. The total inside height, consequently, is 4.695 m. at the axis, the rail being 4.00 m. from the intrados at the keystone and 0.695 m. above the floor. The thickness of the arch at the keystone is 0.50 m., the side walls, 0.60 m. and the floor, 0.55 m. at the lowest point.

On curves having a radius of less than 100 m. for a double track or 50 m. for a single track, the sections specified above would not be wide enough to give the clearance required by law between the cars and the side walls; in such places the width of the tunnel has been adequately increased.

Where Lines Nos. 4 and 8 cross the bed of the Seine, separate metallic tubes will be used. The details of these tubes have not yet been completely worked out, but they cannot differ very much from those of similar works already achieved in England and the United States.

The stations are arched wherever the clearance allows, that is, where there is at least 7 m. between the rail and the surface; they are metal-roofed when this height cannot be obtained.

When the station is arched, Plate XXIX, the section is formed by two semi-ellipses having a common grand axis 14.14 m. long and 1.50 m. above the rail. The first ellipse forms the arched roof and the second, the arched floor; the small axis of the first ellipse is 3.70 m. and that of the second, 2.20 m., giving a total height for the station of 5.90 m. The depth of the arch at the keystone is 0.70 m., and the floor, 0.50 m. The abutments are 2.00 m. thick.

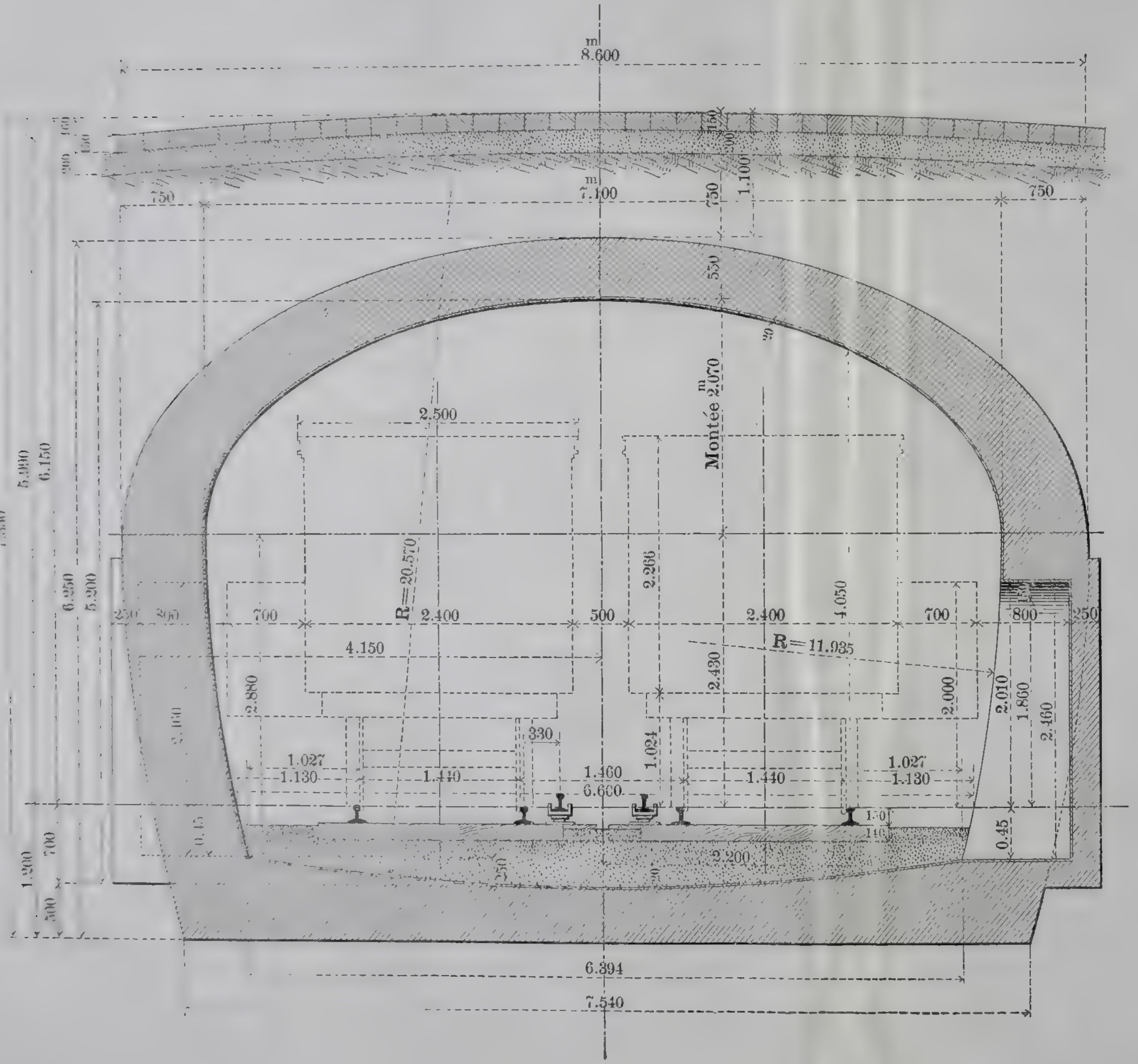
CHEMIN DE FER MÉTROPOLITAIN MUNICIPAL DE

SOUTERRAIN À DEUX VOIES

(TYPE COURANT)

Demi-coupe entre deux niches

Demi-coupe sur une niche



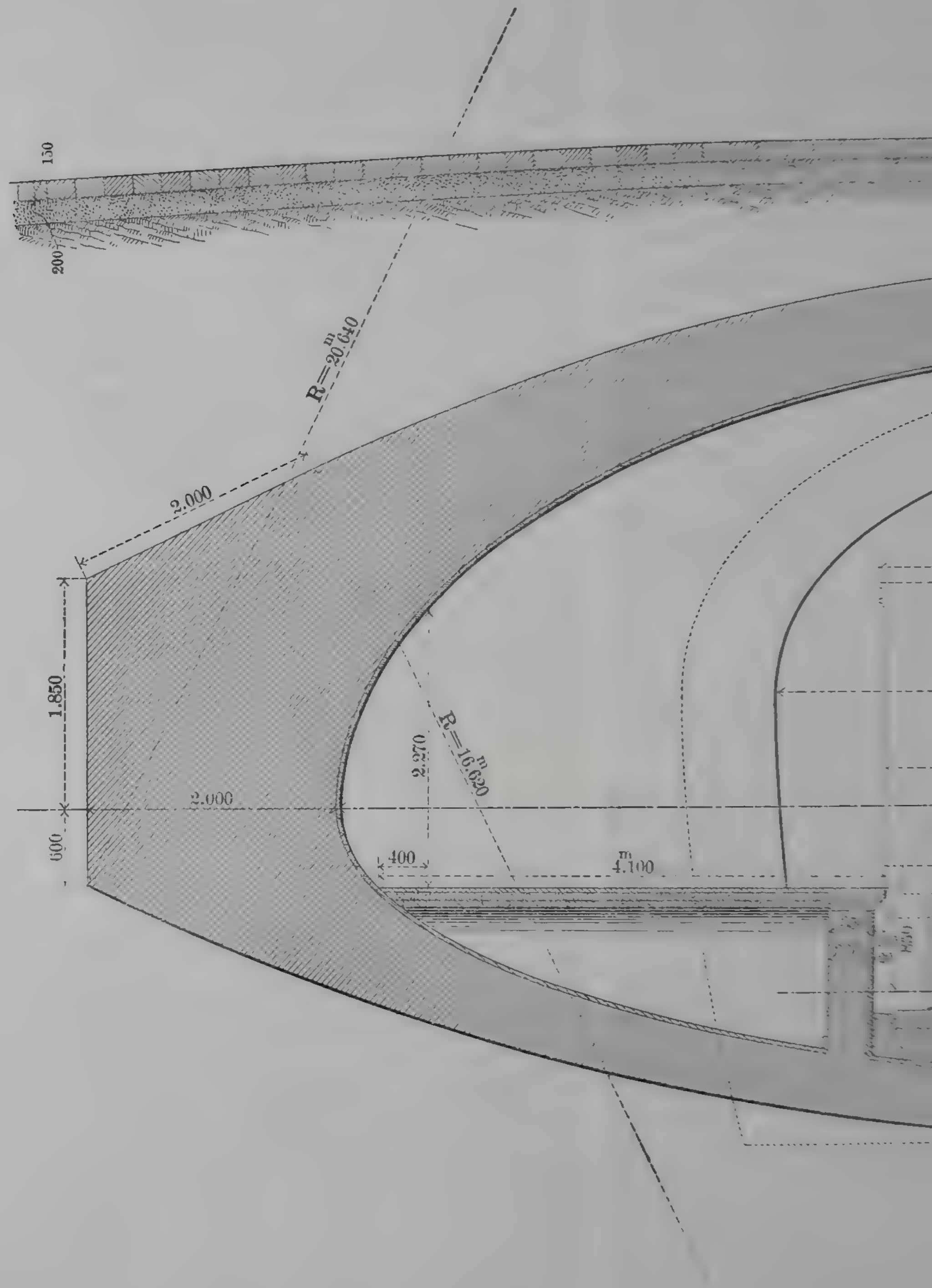
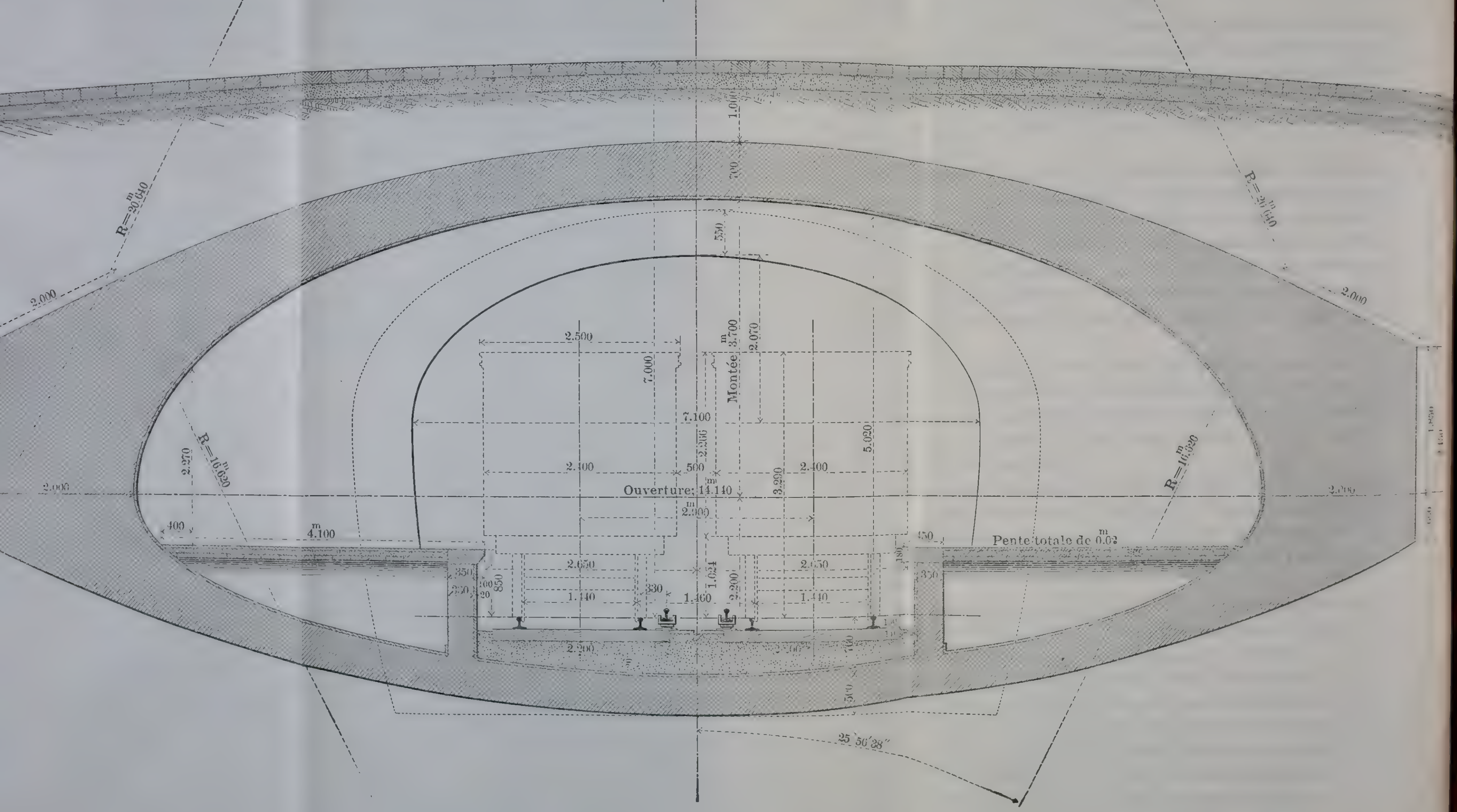


PLATE XXIX. VOL. LIV.
TRANS. AM. SOC. CIV.
INTER. ENG. CONG.,
BIETTE ON
UNDERGROUND RAIL

HEMIN DE FER MÉTROPOLITAIN MUNICIPAL DE PARIS

STATION VOÛTÉE

Coupe transversale



The metal-roofed stations are 13.50 m. wide between walls. The metal roof supported by masonry side walls is 1.50 m. thick at the base and 1.15 m. thick under the beams; between these walls is a concave arched floor 0.50 m. thick. The rail is 4.70 m. below the lower flange of the beams and 0.70 m. above the lowest point of the floor. The roof beams are built beams with solid web measuring 1.02 m. in depth and extend from one side wall to the other without support; they are connected by longitudinal beams parallel to the axis of the track which form springing for small brick arches. This structure supports directly the concrete foundation of the wood paving in the streets.

A standard station, whether arched or metal-roofed, comprises two side platforms 75 m. long and 4.10 m. wide; the level of the platforms is 0.25 m. under the floor of cars, supposed to be new and empty, and 0.85 m. above the rail.

The stations are reached by staircases opening on the streets. These staircases with single, straight flights, and a width of from 3 to 3.50 m. in ordinary cases, lead into underground rooms where tickets are sold. From these rooms, passengers reach the nearest platform by another staircase 2.75 m. wide and the farthest platform by a similar staircase after crossing the railway tracks by means of a footbridge 3 m. wide. The lowest staircases generally pass out to the platforms through apertures in the front walls of the stations and in a few instances through passageways cut through the abutments.

In the elevated parts of the system, the tracks are supported by a metal viaduct formed by a series of separate bents of variable lengths, composed of two side beams supporting the floor system on their lower flanges. These bents are supported on cast-iron columns wherever it has seemed consistent with the strength of the works; where it has been necessary, on account of stability, to adopt masonry pillars, their size has been reduced to a minimum in order to interfere as little as possible with street traffic.

This viaduct is designed so as not to interfere with existing streets. To accomplish this the length of the trusses has to conform at a number of points with local conditions; wherever these conditions do not exist a span of about 22 m. has been found to be best adapted to the various necessities of the construction. Larger spans had to be resorted to in crossing important streets or railroad tracks. For instance, the crossing of the Northern and Eastern Railroads by the Circular Line, on the right bank of the Seine, required three spans 75.25 m. long.

The side beams of the viaducts have **N**-shaped lattices, their lower chords being straight and their upper ones parabolic. Their average height is about one-tenth of the span, and they are either single, or composed of two built beams, according to the distance between supports. The platform is formed of cross-beams; the track is generally ballasted, and the ballast is supported by brick arches connecting the cross-beams. This disposal has been adopted for the purpose of reducing the vibration when the trains pass and of bringing to a minimum the resulting noise and tremors. However, where the spans are longer than usual, the ballasting of the track would increase greatly the dead weight and consequently the cost. The track is then laid directly on a platform formed of cross-beams connected by stringers covered with metallic plates.

In the elevated parts the rail is at least 6.36 m. above the surface of the streets; this distance leaves a clearance of 5.20 m. under the beams, which is sufficient to allow the passage of the highest loads circulating in Paris.

The elevated stations are constructed on the same plan as the viaducts. Each station, with a total length of 75 m., is composed of five independent bents, including four rows of beams. The two inside solid webbed beams support both the floor system and also the station platforms which are 4.10 m. wide; the outside **N**-shaped latticed beams form the second support for the station platforms. An iron and glass roof covers the platforms for the convenience of passengers when the weather is bad.

The elevated stations are reached by a staircase starting from the street and leading to an intermediate floor where the ticket offices are located; from this floor two side staircases reach the platforms at one of the ends of the station.

Special mention must be made here regarding the arrangements adopted both as to the crossings of the metropolitan lines and their terminals.

In a general way, the different lines of the Metropolitan System are independent; they are not connected with one another; at the junctions and points of transfer passengers have to change cars. This system has the advantage of giving more regularity to the operation and of reducing the headway on each line; furthermore, it lessens a cause of accidents, *viz.*, the collision of trains at switching points, which danger grows in proportion to the number of trains. It is to be feared, however, that this rule cannot be adopted absolutely, and that in some of the new lines of the projected system it will be necessary to have grade switches; if this cannot be avoided the switches for trains coming toward the main line will be placed immediately beyond the station, so as to reduce to a minimum the risk of collision.

The headway between trains on the Metropolitan System is very short; it is necessary to avoid any loss of time caused at the terminals by switching, and this loss of time has been avoided by building loops which permit the trains to pass directly from the arriving to the starting point. These loops are installed according to local conditions and the space it is possible to use. In some places, at the terminals of Line No. 1 situated in wide avenues for instance, two separate stations have been built, one for incoming and the other for outgoing trains, and the ends of the stations have been connected by a loop of small radius. In other places, at the Place de la Nation Terminus of Line No. 2, right bank, for instance, the track describes a loop with a radius as long as possible, and the terminal station is located on the loop. By this second method, moreover, if the loop is double-tracked, the terminal is provided with side-tracks which allow the storage of reserve trains and also of service trains at hours when traffic is lightest.

It would be too tedious to enter into minute details concerning these different methods, but exhaustive information on the subject can be found among the collection of drawings pertaining to the Municipal Metropolitan System exhibited by the City of Paris.

The masonry used in the Metropolitan System is made almost exclusively with cement mortar. This mortar sets more rapidly and its resistance is stronger for the same thickness. It is hardly necessary to point out that rapid setting for masonry is necessary for underground works, and that stronger resistance is cheaper in the end. Lime has been used only in exposed masonry such as, piers supporting the iron structure in the elevated parts of the system.

In underground work, two kinds of masonry are used: *meulière* masonry and concrete. The first is used for arches and the second, for side walls and floors.

The *meulière* used is a silicious, light, and porous stone, which easily takes the mortar and is found around Paris, chiefly in ground of tertiary formation. The pebbles used for the concrete are found in great numbers in the alluvions of the Seine basin.

The cement used is a slow-setting Portland cement or a slag cement. The Portland cement mortars are mixed at the ratio of 300 kg. per cu. m. of sand when they are used for masonry and at the ratio of 400 kg. for the same volume of sand when used for concrete. The slag cement mortars are proportioned at a ratio of 50 kg. more.

The concrete is composed of 0.80 cu. m. of broken stone for 0.55 cu. m. of mortar.

Cut-stone masonry is used for exposed structures, such as great bridges on the Seine, supports for viaducts, works at points where the road changes from elevated to underground.

Inside the stations all visible facings are covered uniformly with white tiles made of enameled ceramic sandstone, or of opalin or even sometimes of enameled bricks. All other works are coated only with cement: quick-setting Vassy cement for the arches, and Portland cement for side walls and floors.

* * *

The viaducts and generally all metallic work such as bridges, roofs of tunnels or stations are made of soft rolled steel elongating 23% under a breaking load of 43 kg. per sq. mm. of section.

The achievement of a metropolitan system makes necessary certain preliminary work, *viz.,* diverting sewers, water mains and other conduits, filling in of the underground, often undermined by abandoned quarries, for the purpose of providing space and preparing the ground for the construction of the track. This preliminary work as well as the construction itself, is let out by public tender which is always compulsory in France for the execution of public works. Each line is divided into sections, generally about 1 000 m. long, and never more than 1 500 m. long for underground work. For the elevated parts the length of the sections is limited to about 900 m. Each contractor has a time limit fixed for the completion of his work and generally this limit is calculated by allowing one month for 100 m. underground and three months extra for the preliminary organization of plant. A large premium is given for each day gained on the limit fixed and an equal fine imposed for each day of delay. By this arrangement the work is completed in a comparatively short time. Line No. 1, the first built, with a length of 10.5 km., was finished in 17 months of actual work, and Line No. 2 on the left bank of the Seine, with a length of 9.4 km., was finished in 18 months.

On each section there is, generally, only one point at which ground is broken, but other secondary points are sometimes authorized, as at stations or other works of special importance. At such points the contractor sinks vertical shafts in which electric elevators are installed for hoisting excavated material and lowering materials of construction.

In the ordinary construction of the tunnel, the method followed is nearly always to construct the arch first, the side walls next and then the floor.

For stations, however, and arches of special works where the span is more than 10 m., the side walls, or abutments, are first constructed in galleries and then, as the case may be, the arch is constructed or the metallic roof put in position; the core of the tunnel is then excavated, and finally the masonry for the floor is laid.

On Line No. 1, from the Porte de Vincennes to the Porte Maillot, the first line built, it was understood that the arch of the ordinary doubled-tracked tunnel would be constructed principally with the shield device. As is known, this device consists of a kind of metallic shell, behind which the digging and lining of an underground gallery proceeds, and which is pushed progressively as required, holding the ground in the meantime. Only a few words will be said concerning this invention of the French engineer Brunel. It was applied by him in tunneling under the Thames in 1825 and contains the nucleus of all improvements achieved since on the same lines. Forty years later the Englishmen, Barlow and Greathead, following the same idea, applied the shield to the construction of cast-iron circular linings. It is under this form that

M. Jean Berlier made it popular in France at the beginning of 1887. The latest French shields applied in the construction of masonry arches are somewhat similar to the first device invented by Brunel, and these are the kind used on the Metropolitan. They have been little used, however, on account of the excessive delay of the manufacturing plants, and also on account of the slow work of imperfect devices. When Line No. 1 was being built, time was too short to permit experiments, and it became imperative to use other means of construction better adapted to the circumstances. Under such conditions the experiment of constructing the tunnels of the Metropolitan by means of shields has not proved very conclusively the value of this device. It may be said, however, that the shields supposed to be of the best construction have not given the satisfaction expected. It was expected particularly that the use of the shield would prevent most of the breaking up of streets, but better results have not been obtained than with the timbered headings. It may be said, however, that, if the shield works satisfactorily in the construction of a tunnel in uniform ground or when the tunnel is to be made of a strong lining like cast-iron tubes, the result is entirely different when the purpose is to build a masonry gallery in ground with as little uniformity as is found in the Parisian subsoil, particularly near the surface. Excavations, bad fillings, foundations of old buildings, which are often quite important and which prevent a regular advance of a mechanical device, are often encountered. Besides it is often necessary in such ground to increase the strength of masonry work either by reducing the outside cross-section or by increasing the thickness; such modifications are hard to make when the shield is used. In fact on the other lines its use has been discarded in favor of the standard method of timbered headings, more easily controlled and better adapted to this kind of work under actual conditions.

Of this timbered-heading method, as used to-day, little can be said which is not known already. The advance heading is dug at the highest part of the tunnel, and the arch is constructed by cutting. At certain points satisfactory results have been obtained by digging two headings simultaneously, one at the top and the other at the bottom of the tunnel, the last one being kept about 50 m. longer than the first. The lowest heading is used to carry out the diggings and the upper one, to bring in the materials for building the arch. This process which, however, can be applied only in solid ground, simplifies very much the organization of the plant.

The arch masonry is made generally by rings 3 m. long. The side walls are built from the arch down in sections whose width varies with the firmness of the ground encountered; where the ground is solid the bench is nearly all taken out before the walls are begun; where, on the contrary, the ground is likely to cave in, side trenches of variable dimensions are cut before the bench is taken out.

When the arch and the retaining walls are completed, grout is injected systematically behind the masonry so as to fill all empty spaces which are likely to remain between the masonry and the ground. These injections are made through holes left in the masonry during the construction; they are made over the whole surface of the arches and to 0.50 m. below the springing. Cement mortar gauged at the ratio of 650 kg. of Portland cement per cu. m. of screened sand, is injected with the Greathead injector or a similar device. The usual pressure is from 2 to 3 kg.

The standard cross-section defined at the beginning of this paper is of course reinforced in ground without any solidity or when the tunnel has to support exceptional loads, as, for instance, when it passes under other galleries. This reinforcement is made, however, in a way which does not call for any particular description.

For quite a long distance, the tunnel runs under counter-alleys or wide gravel sidewalks planted with trees, so that during the rainy season, or when the trees are watered, troublesome infiltrations penetrate through the masonry if special precautions are not taken. The method adopted has been to dispose small circular conduits with a diameter varying from 0.06 to 0.07 m. and opening under the floor, carefully along the inside surface of arches and walls. The water drained into these conduits is absorbed in the adjacent subsoil or is carried to drainage wells. In order to make these conduits in the arches, straw strands are embedded in the masonry when building, but not so deep as not to appear on the intrados. After taking down the centers, these strands are removed and replaced by rubber tubes; a coating of quick-setting cement mortar is then applied to the tubes and the conduits are made by removing the rubber tubes.

In the parts of the tunnel constructed entirely in water-bearing ground, the following process has given good results in keeping out the water. The masonry is constructed in a single ring along the whole development of side walls and floor. There are two layers of masonry separated by an inside cope, 0.030 m. thick, made of compact, tempered, well-rammed, cement mortar. The cement used is Portland cement gauged in proportions of 650 kg. per cu. m. of sand, or, quick-setting Porte-de-France cement gauged at 1 000 kg. per cu. m. of sand. The cope is made with the greatest care without any solution of continuity, and each new section is carefully joined to the last one, whose end is scraped and washed. As soon as the cope is finished on the surface of a ring, the second layer of masonry is begun, care being taken not to injure the cope. The inside coating of the tunnel is highly polished.

At the place where Line No. 3 crosses under the St. Martin Canal at the Avenue de la Republique, the tunnel is laid entirely in aqueous ground for a length of 76 m. and partially for 340 m.; it has been constructed as explained above, and the infiltrations do not exceed 550 liters per 24 hours which is equal to 0.0064 liter per second.

One of the most intricate problems to solve in the construction of the Metropolitan Railway has been the removal of the excavated material and the carrying in of materials of construction. If it is considered that when the bench is removed an average section produces from 800 to 1 000 cu. m. per 24 hours, it is easy to understand how difficult it was to remove such an amount of earth by means of ordinary carts in the center of the heavy traffic of Paris. Methods more modern, more rapid and more economical have been sought. For instance in the central part of Line No. 1 running at a short distance from the Seine, the contractors did not hesitate to build special galleries many hundreds of yards long in order to connect the tunnel with the Seine and thus allow the removal of the excavated material by boats. At other points the street car tracks connecting with the suburbs of Paris have been taken advantage of; spurs have been constructed from these tracks to the elevators in the working sites so as to allow the direct removal of excavated material without reloading. Even on Line No. 3 the earth coming from the central sections near the St. Lazare Station, the Opera and the Bourse, has been carried beyond Paris by means of a temporary spur specially constructed to connect with the Ouest Railroad.

* * *

It has been said previously that the tunnel of the Metropolitan Lines ran as closely as possible to the surface of the public streets. There are some exceptions to this rule brought about by obstacles encountered in the Parisian subsoil and which it has not always been possible to get rid of, such as the great collecting sewers which are not easy to displace, the Seine, and the navigable canals, the great railroads and finally the Metropolitan Lines themselves where they cross each other. To overcome such obstacles, special arrangements have to be adopted, and the work is sometimes very difficult. Among the various difficulties encountered, a few characteristic examples are given.

Line No. 1 from the Porte de Vincennes to the Porte Maillot crosses four important sewers: at the crossing of the Boulevard Diderot and the Rue Crozatier; at the crossing of the Rue de Lyon and the Avenue Ledru-Rollin; at the junction of the Rue de Rivoli and the Boulevard Sebastopol, and finally, at the Place de la Concorde. Line No. 3 from the Boulevard de Courcelles to Menilmontant meets the St. Martin Canal at the junction of the Avenue de la Republique and the Boulevard Richard Lenoir. At these different points it was necessary to lower the longitudinal section of the Metropolitan System in order to pass under these obstacles. The difficulty of working under important galleries, the security of which it was essential to maintain, was increased by a section of aqueous subsoil encountered at these different points at a comparatively short distance from the surface. For instance, at the Boulevard de Sebastopol, it was necessary to lower the rail 13.70 m. from the roadbed, and the bottom of the tunnel was 5.36 m. under the sheet of underground water. Where the St. Martin Canal crosses Line No. 3, the rail has been placed 19 m. under the roadbed and the tunnel is entirely in the sheet of water. Fortunately the rough calcareous stratum which forms a solid base, follows the alluvion closely and makes it possible to take care of the flow of water by ordinary means. At each crossing a well sunk through sand and marl under the bottom of the tunnel insures the drainage of the sand the whole length of construction, and rotative pumps driven by electric motors have sufficed to keep the water lower than the tunnel works during the whole period of construction. The masonry has been the object of special precaution. Its thickness has been increased and upon the whole length of the crossing of the water sheet, the intermediate cope, described elsewhere, has been resorted to. The proportion of cement in the mortar has been increased also to the amount of 550 kg. per cu. m. of sand. Besides the St. Martin Canal has been kept dry during the construction of the railway; the collecting sewers have been kept in service but their masonry has been detached, and the sewage made to run in iron pipes laid above the crossings with their ends supported in temporary walls acting as dams. The different works crossed in this way have not been injured in the least except for some crevices in the masonry which have been easily filled by grouting under pressure.

Lines 2, 4, 6 and 8 cross the Seine, the first and last, twice; the second and third, once. Lines 4 and 8 will cross underneath. The crossings will be made in metallic tubes, but have not been commenced as yet. The crossings of Lines 2 and 6, actually in course of construction, are elevated. They will be made on large viaducts which will take too long a time to describe, and which, moreover, are only characterized by the importance of the work necessary. However, the building of the Passy Viaduct, at the crossing of the Ouest Railroad, has given rise to some interesting preliminary work of which the following short description is given.

The Passy Viaduct which is metallic and double-decked, one deck for carriage traffic and the other for trains, occupies exactly the same space used formerly as a footbridge across the Seine, connecting the Boroughs of Passy and Grenelle. It was necessary, therefore, from the beginning of the work to do away with this footbridge, but it was also essential not to cut the connection between the banks of the Seine. Consequently it was resolved to move the footbridge and carry it back parallel to itself sufficiently to allow room necessary for the working sites of the viaduct. This footbridge comprises two similar parts which correspond to the two arms which form the Seine at this place. Each part, of the cantilever type, was formed by a central arch, jointed from the crown, resting on two piers in the river and anchored by two abutments resting on the banks. The footbridge above the wider arm had a total length of 120 m., a width of 650 m. and a weight of 320 tons; the part above the smaller arm had a total length of 90 m., a width of 6.50 m. and a weight of 240 tons. These two parts have been moved separately and each by a different method.

The following method has been adopted on the wider arm of the Seine where boat traffic is considerable. Rolling timber platforms, supported on piles, have been disposed in the river and on the shores, near each anchorage in the moving direction. A platform has been built near each abutment. Similar installations were made on each side of the two piers in the river. Wooden girders corresponding to the different rolling platforms were placed under the footbridge which was then raised and laid on rollers; its moving was secured by tackles operated by hand windlasses. The total traction power used was 48 000 kg., each windlass being operated by four men. By the operation of the windlasses, the footbridge moved very smoothly and regularly. The displacement which attained a length of 30 m. was made in four hours without the slightest trouble and without having interrupted in the least the traffic on the river.

On the small arm of the Seine where the boat traffic is very light, the footbridge was moved by raising each half, after removing the key joint, by two barges conveniently unballasted, which were set adrift and ballasted again when once brought back to their final positions. The barges used were 30 m. long, 5 m. wide and able to carry 280 tons at full load. This displacement, although hindered by a very strong wind, did not take more than 1.25 hours and was effected without accident.

The crossings of the Metropolitan System which deserve special mention are: the crossing of the Nord Railroad by Metropolitan Line No. 2, right bank, and the crossing of Line No. 2, left bank, under the railroad from Paris to Sceaux and Limours.

At the crossing point with the Nord Railroad, the Metropolitan Line No. 2, right bank, is elevated. The width of the crossing made a 75.25-m. span necessary, and the corresponding span had to be of same length to provide for a future widening of the railroad. The common support for these bridges had to rest on one of the railroad bridge abutments, the railroad itself crossing the street in a cut. But this abutment which was only 2 m. wide, was not strong enough to support the weight of the bridges of the Metropolitan which was 940 000 kg. The Nord Railroad Company had prescribed the condition that the thickness of this abutment should not be increased by more than 0.50 m. In order to conform with this condition two metallic pillars have been added to the new masonry in order to transfer the weight of the bridges of the Metropolitan Railway directly to the foundation. These caisson-shaped pillars are made of rolled steel plates and angles; they have been filled with a thin Portland concrete increasing their rigidity and protecting them on the inside from rust.

Metropolitan Line No. 2, left bank, crosses under the line from Paris to Sceaux and Limours (Orleans Company) at the Place Denfert-Rochereau. The difficulties of the crossing, great already by reason of the large number of suburban trains passing above, were increased by the following circumstances. At the crossing is a station of the Sceaux Railroad formed by a cut covered with a metallic roof. The ground is there already undermined by galleries and cave-ins of old stone quarries, and this circumstance had obliged the Orleans Company to consolidate the ground thoroughly right under the side walls and the supports of the metallic roof of the suburban station which they were building. A sewer which is necessary to the operation of the Orleans Railroad runs between the arch of the Metropolitan station and the floor of the Orleans station. Finally in the immediate neighborhood of the crossing is a very important group of water mains, which supply Paris with water and with which the company could not interfere. All these difficulties, to be dealt with in a comparatively small space, have made the engineering work very troublesome, but they have been overcome in the following manner.

In the first place, the foundations for the supports of the metallic roof of the suburban station have been continued from under to the level of the floor of the Metropolitan station. Then the side walls of the Metropolitan tunnel have been built. The thickness of these side walls has been increased from 0.75 to 2 m., and each one has been constructed by means of superposed headings

2.40 m. high. There were three headings at the crossing of the Sceaux Railroad and four under the suburban station. The headings were undertaken by stages and opened at the same time, at both ends of the Metropolitan tunnel, one for the right side wall, the other for the left side wall. The masonry was laid temporarily on their outer surface only, so as to leave a passageway for removing the earth and carrying in the materials; the headings were filled with masonry when they were no longer required as passageways. The side walls being finished, the construction of the arch has been commenced by breaking up and enlarging the heading according to the usual method; but in order to avoid any settling later on, iron sheets 18 mm. thick and 0.20 m. wide, embedded afterward in liquid mortar injected from holes left in the masonry, were substituted for timbers for the sheeting of the roof of the tunnel. The foundations of the pillars of the station supporting the metallic roof have been joined also to the arch to which they have been bound by I-beams, 0.16 m. high. The arch once built, the bench and the concrete piers which formed the underpinning of the pillars supporting the metallic roof have been removed, and finally the floor has been constructed. In order to support the works of the Paris and the Sceaux and Limours lines, the only precaution taken was to place the tracks upon strong oak stringers a little longer than the width of the crossing. The only disturbance occasioned in these works by the Metropolitan tunnel construction has been a few crevices in the side walls; these crevices have been filled by injections of grout.

Line No. 3 connects with the Circular Line, right bank, at the Boulevard de Courcelles between the Boulevard Malesherbes and the Avenue de Villiers. Originally this connection was to be on the level, so that for a certain length, the tunnel has been made 18 m. wide in order to accommodate four tracks and junctions between the two lines for handling the empty cars. This 18-m. arch with its extrados only 1 m. below the surface of the boulevard on which are street railways run by mechanical traction, had been built without very much difficulty, until it was decided to provide for a possible extension of Line No. 3 toward the periphery. This extension being only possible by a crossing under Line No. 2, right bank, it became necessary to deepen the tunnel common to both lines in that part apportioned to Line No. 3, and to build at once the crossing of this line under the side wall of the great 18-m. arch and thus avoid doing this work when Line No. 2 was being operated, as this would then be almost impossible. Deepening Line No. 3 has led to the underpinning of one of the side walls of the 18-m. arch and this underpinning was at some points 7 m. deep. It was done by alternating cross trenches, each 2 m. wide, and, owing to the exceptional solidity of the ground which, in this neighborhood, is of calcareous lacustral formation, no difficulty was encountered. The crossing of Line No. 3 under the other side wall of the 18-m. arch having a bad slanting direction, two galleries joined together by a single track have been substituted for the standard type of tunnel. These galleries have been dug, with the greatest care, by successive rings 1.50 m. wide; the arch above has not been affected perceptibly.

Line No. 3 crosses at the Place de l'Opera above two other Metropolitan lines: Line No. 7 from the Palais Royal to the Place du Danube and Line No. 8 from Auteuil to the Opera. Line No. 3 having been constructed first, it was necessary to complete the works of the two other lines at the crossing point at the same time, in order to avoid the necessity of working, later on, under a line in operation. But the rail of Line No. 7 at the crossing point was about 11 m. below the surface and that of Line No. 8, a little more than 16 m., the masonry common to the three lines, and which has to go 20 m. under the surface, was at a height of about 9 m. in the underground water sheet, which is encountered there about 12 m. below the surface. Compressed air was then resorted to for the foundations of the work common to the three lines. The supports were furnished by three caissons, one 8.25 by 6.00 m., the other 19.50 by 8.00 m., and the third, 24.50 by 8.00 m. The first caisson sunk on the Place de l'Opera supports the side walls of Lines Nos. 3 and 7 at their first crossing point, the other two placed parallel to the axis of the Boulevard des Capucines encircle the tunnel of Line No. 8 and support the works of Lines Nos. 3 and 7. The sinking and placing in position of these caissons was not made without some difficulty owing to their position at a crossing where it was necessary to leave room, without great inconvenience, for very heavy street traffic. Beginning with the 9th of May, 1903, for the first caisson, the 19th of June for the third and the 31st of July for the second, the sinking was finished, without trouble, on August 31st. Then the masonry for the work on Line No. 3 was undertaken, followed by the laying of the metallic roof over which it crosses Line No. 7 and finally by the placing of the metallic roof near the street surface. The covering of the whole work was completed and the street reopened to traffic on December 27th, 1903, nine months after the beginning of the work.

Finally some information will be given concerning the exceptional difficulties, owing to the formation of the subsoil, encountered in the construction of Line No. 3 at the Terminal Menilmontant under the Avenue Gambetta and the Rue Belgrand. On these two routes, after the Place Martin-Nadand, the subsoil is composed of gypsum marl, but this marl forms the bottom of a basin filled with either clayish earth or fine sand both impregnated with water; the clay predominates under the Avenue Gambetta, the sand under the Rue Belgrand. Such ground renders tunneling extremely hazardous and difficult, principally where, as in the present case, it must proceed in the neighborhood of buildings, the foundations of which had not been constructed in view of this occurrence. The fine sand impregnated with water forms a particularly troublesome element if its nature cannot be modified. Under such circumstances the work had to be done by a method entirely different from the ordinary one, and the side walls were first undertaken in such a way as to obtain the drying of the thin sand. For this purpose a large number of wells have been sunk from time to time through the sand to the layer of marl where the foundations can be laid safely. These wells, sunk with all the care necessary on such ground, have been provided with permanent means of drainage and by their continued operation have caused this naturally semi-fluid ground to become firm enough to permit of the construction of the tunnel. Most of these wells having been sunk on the line of the side walls, it has been sufficient to construct these walls and to fill up the wells with concrete; but care has been taken first to place a longitudinal drain-pipe at the bottom, which takes the water to an end sump sunk by compressed air, whence it is pumped into the sewer. It is hoped in this way to drain the ground sufficiently to allow the arch and the floor of the tunnel to be constructed without great difficulty.

* * *

The details described above give an idea of the conditions under which the Municipal Metropolitan Railway of Paris has been planned and is being completed. They show the many difficulties encountered during the construction of an undergound railway in a large city, and they also show how to overcome these difficulties by different methods adapted to local conditions.

Up to the present time the construction of the Metropolitan Lines in Paris has progressed rapidly; and a considerable advance, viewed from the length of actual construction, on the time allowance granted by the franchises is noticeable. Perhaps for some of the sections not yet commenced this length of construction will be increased slightly, but every effort will be made to save time. Here, perhaps, more than anywhere else, speed is a condition essential to success.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 89.

UNDERGROUND RAILWAYS.

UNDERGROUND RAILWAYS IN GREAT BRITAIN.

By Basil Mott and David Hay, Members, Inst. C. E.

The construction of Underground Railways, properly so-called, in England, with the exception of the Glasgow District Subway and the Mersey Railway at Liverpool, has been confined to London. The transit facilities of large provincial towns are supplied by cabs, tramways, omnibuses, and surface and overhead railways, but these, in the majority of cases, are notoriously inadequate.

In London the Underground Railways are of two distinct types, *viz.*, railways constructed just below the surface and approached by stairs from street level, and deep-level, or tube railways, constructed in the London Clay at depths varying from 40 to 100 ft. below the surface, and approached by lifts. The general arrangement of these railways, both shallow and deep-level, is shown on Plate XXX.

"Shallow" Railways.

It is just fifty years since an Act of Parliament was obtained for the construction of the first length of Underground Railway in

England. This railway was entitled the "North Metropolitan Railway, Paddington, to the Post Office, Extensions to Paddington and the Great Western Railway, the General Post Office, the London and North Western Railway and the Great Northern Railway." Acts for extensions were obtained subsequently, and the various sections of the railway, which now constitute the Inner Circle of the underground system of London, were completed and opened for traffic as follows:

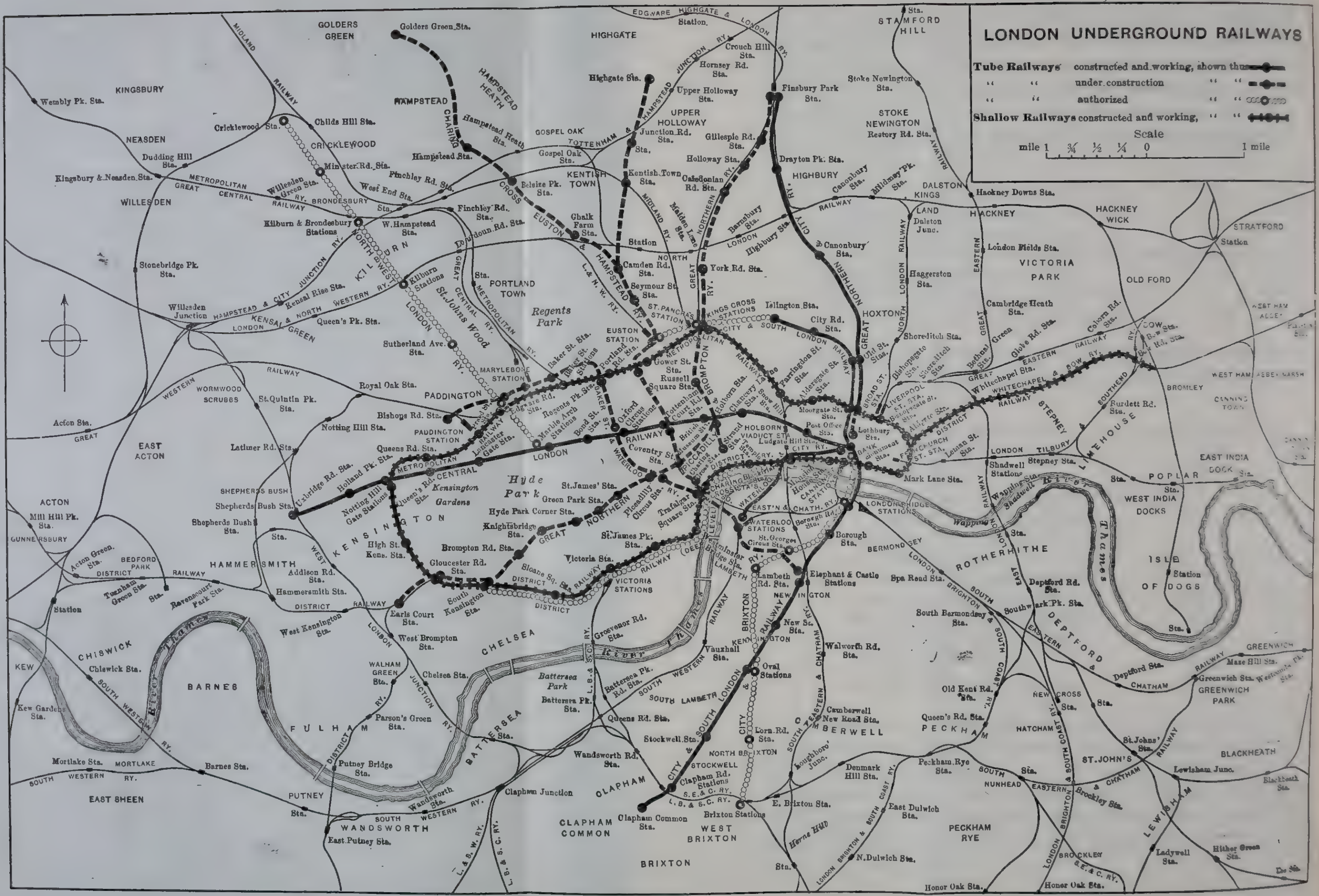
Paddington to Farringdon Street	(Metropolitan Railway).		1863
Farringdon Street to Moorgate Street	"	" ..	1865
Paddington to South Kensington	"	" ..	1868
South Kensington to Westminster	(Metropolitan District)		1868
Westminster to Mansion House	"	"	1868
Mansion House to Aldgate (Joint Lines)			1876
Aldgate to Moorgate Street (Metropolitan)			1884

Other extensions and connections, which, however, are only partly underground, have also been constructed, of which the following are the most important:

Hammersmith and Paddington	opened	October,	1863
Baker Street and Swiss Cottage	"	April,	1868
East London Railway			
New Cross to Wapping (through Brunel's old Thames Tunnel)...	"	December,	1869
Wapping to Whitechapel (Great Eastern Railway)	"	"	1876
Connection with District Railway...	"	"	1884
Hammersmith and Ealing	"	July	1879
Earl's Court to Putney Bridge	"	March,	1880
Putney Bridge to Wimbledon	"	June,	1889
Whitechapel and Bow	"	May,	1902
Ealing and South Harrow	"	June,	1903

These shallow lines, with two exceptions, were constructed more than ten years ago, and therefore do not come properly within the scope of this paper, but the question of London Underground Railways cannot be dealt with, however shortly, without mentioning these important lines, which, with few exceptions, were constructed on the familiar cut-and-cover system, type-sections of which are shewn on Plate XXXI.

PLATE XXX. VOL. LIV. PART F
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
MOTT AND HAY ON
UNDERGROUND RAILWAYS.



LONDON UNDERGROUND RAILWAYS

DEEP-LEVEL TUBE RAILWAYS.

The enormous cost of constructing the "shallow" railways through the busy centers of London is, under existing circumstances, prohibitive, and, with the exception of the "Whitechapel and Bow," no such railway has been carried out since the completion of the circle from Aldgate to Moorgate Street, in 1884. In order to avoid this heavy capital expenditure, the late Mr. J. H. Greathead proposed the alternative system of deep-level, iron-lined, tube railways constructed in the "London Clay," which is a strong impervious clay, and extends practically under the whole of the Metropolitan area.

With the exception previously mentioned, this system has been adopted for underground railway extensions in London since the completion of the Inner Circle in 1884, and, at present, the number of existing lines, under construction or authorised, is as follows:

City and South London Railway.........	Open for traffic, 1890
Waterloo and City Railway..............	" " " 1898
Central London Railway.................	" " " 1900
Great Northern and City Railway........	" " " 1904
Baker Street and Waterloo Railway......	Under construction.
Great Northern, Piccadilly and Brompton Railway..........................	" "
Charing Cross, Euston and Hampstead Railway..........................	" "
North West London...................	Authorised.
District Deep-Level....................	"

The limits of one paper will not allow of a detailed description of all London tube railways, and the method of construction of these shield-driven tunnels has often been described, and is too well known to engineers to call for repetition. The main features are practically the same in all cases, and may be summarised briefly as follows:

The tunnels are all iron-lined tubes, circular in section, constructed under the streets, to avoid the purchase of property, and at a sufficient depth to prevent interference with pipes and sewers.

The station tunnels, containing the platforms, etc., are generally 21 ft. 2½ in., internal diameter, and from 300 to 400 ft. in length, lined with concrete and tiled. The average distance apart of the stations is ½ mile.

The only property purchased is for the surface stations and the power station. Upon the station sites are sunk the shafts for lifts, and stairs communicating with the platforms. The lifts are an essential feature of deep-level tubes, and though adding to the cost of working the line, they enable the tunnels to be constructed in the London Clay, and have been generally adopted. These lift shafts are utilised during construction as working shafts from which all the tunnels are driven, and no openings of any kind are required in the streets; consequently there is no disturbance of traffic.

The main up and down lines are in separate tunnels of an average internal diameter of 11 ft. 6 in. The advantage of separate tunnels is considerable, for the following reasons:

1.—In narrow streets, where a single double-line tunnel would be impossible, without encroaching upon adjoining property, the two tubes can be placed one over the other without difficulty, and no property need be purchased.

2.—The ventilation is assisted materially by the trains moving always in one direction in each tunnel.

3.—The gradients approaching and departing from the stations can be arranged to give a steep gradient with the load when departing from stations, and a moderate gradient against the load on approaching stations. The departing gradients, where feasible in practice, are made 1 in 30, with a fall of 10 ft., which secures a very rapid acceleration and reduces the power required approximately 25 per cent. The approaching gradients are usually from 1 in 60 to 1 in 100. With both lines in one tunnel the gradients with, and against, the load are necessarily the same.

4.—Where headway is important in passing under existing railways, or deep-level sewers, etc., two tunnels have an advantage.

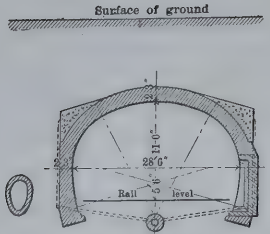
5.—Two small single-line tunnels are cheaper than one large double-line tunnel.

Electric traction has been adopted as the motive power on all lines.

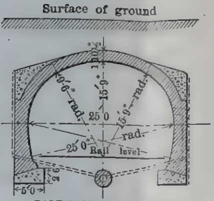
City and South London Railway.

The pioneer of all tube railways is the City and South London Line, and, therefore, the following brief description of its early history, with details of some features of special interest in its construction, may be justified.

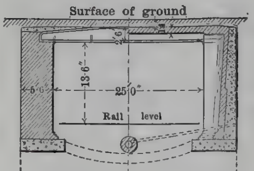
GLASGOW DISTRICT SUBWAY



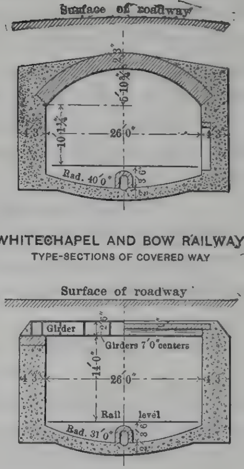
METROPOLITAN RAILWAY
TYPE-SECTION OF COVERED WAY



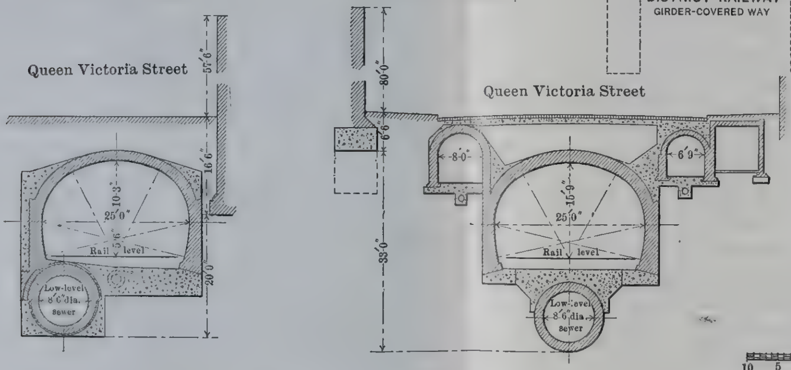
DISTRICT RAILWAY
TYPE-SECTION OF COVERED WAY



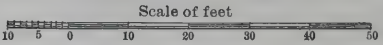
DISTRICT RAILWAY
GIRDER-COVERED WAY

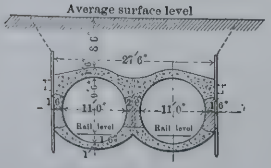


WHITECHAPEL AND BOW RAILWAY
TYPE-SECTIONS OF COVERED WAY

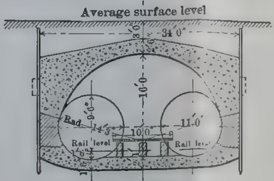


DISTRICT RAILWAY
CONSTRUCTIONS IN QUEEN VICTORIA STREET

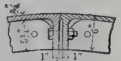




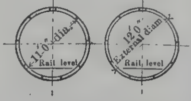
TYPE-SECTION OF COVERED WAY



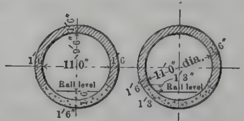
TYPE-SECTION OF COVERED WAY AT STATION



DETAIL OF HORIZONTAL AND CIRCUMFERENTIAL FLANGES



IRON-LINED TUNNELS.



BRICK AND CONCRETE-LINED TUNNELS.

As originally designed and carried out under the late Mr. Greathead, the line ran from "The Monument," in the City of London, to Stockwell, south of the Thames, a length of a little more than three miles, and the first Act was obtained in 1884.

Commenced in October, 1886, from a temporary shaft which had been previously sunk in the river near the North Bank, it was completed and opened for public traffic in December, 1890. The running tunnels on the first section (City to Elephant and Castle) were 10 ft. 2 in. internal diameter, and thence to Stockwell, 10 ft. 6 in., with enlargements at intermediate stations to 20 ft. for each line and 26 ft. for terminal stations.

Under the Act of Parliament, the use of steam locomotives was prohibited, the original intention being to use an endless-cable system of haulage. This idea, however, was abandoned and electric power decided upon. The greater part of the tunneling was carried out with a shield, in the ordinary way, through the London Clay, but at certain points depressions in the clay occurred, and the work had to be done through water-bearing gravel and sand. The largest of these depressions occurred near Stockwell, where the gravel was of such an open nature, and contained such a large quantity of water, that the use of compressed air had to be resorted to. The greatest difficulty was experienced at first in making any progress at all. Eventually, it was found necessary to "close-pole" every length in front of the shield, and force lime grout, under high pressure, through holes drilled for the purpose, in the poling boards. By this means it was possible to prevent the escape of air, and obtain a sufficient pressure (about 15 lb. per sq. in.) to keep back the water. Progress was necessarily somewhat slow, from 4½ to 5 ft. of 10 ft. 6 in. tunnel being driven per day. The writers believe that this was the first instance of any magnitude, certainly in England, in which tunneling was carried out through such material, and, although there were very large high-pressure gas and water pipes, tramways, etc., overhead no subsidence took place.

The railway was opened from the City to Stockwell in December, 1890, but it soon became apparent that the maximum carrying capacity of the line was insufficient to make the undertaking a financial success. The railway was evidently too short, some of the curves and gradients near the City, designed originally for cable traction, were unsuitable for rapid service, and the terminal station in the City was too short to allow of the trains being lengthened. It was not possible, for various reasons, to alter any of these defects in the City, and it was decided to construct new tunnels under the river (this time east of London Bridge), and to carry the line through the City and as far north as the Angel at Islington. At the same time the line was extended another mile southward, *viz.,* from Stockwell to Clapham Common.

These extensions, for which Acts were obtained in 1890 and 1893, necessitated the construction of junctions with the existing lines on the south side of the river, without interrupting the train service. The operation was one of considerable interest and some difficulty.

Fig. 1 shows the plan and cross-sections of one of these junctions on the up line. The original tunnels are shown in dotted lines, and it will be observed that the new tunnels, as far as possible, were made large enough to give working space around the old tunnels. In this way the tubes containing the running roads were preserved intact until the new tunnels were completed. Fortunately, the ground was good, and the work was carried out successfully without any interruption of the traffic, and without any damage to the buildings abutting on the streets above.

Another feature in connection with this extension was the construction of the "Bank Station." Under the Act of 1893, the company was empowered to acquire, for the station site, the Church of St. Mary Woolnoth, which stands at the junction of Lombard Street and King William Street, in the City of London.

Some public outcry was raised about the wickedness of demolishing the building, and, in deference thereto, the company undertook to uphold it, and to use only the subsoil for the purposes of the station. This involved carrying practically the whole of the church on girders and columns in order that the lift shaft, the waiting and exit halls, etc., might be constructed underneath. Fig. 2 shows a plan of the church at the ground level (church floor removed), with the main girders, the needles supporting the walls, and round stone columns. These columns, four groups of three in each group, supported the "fair square" roof (see Fig. 3, section on Line *C-D:* also Fig. 2), and also half the weight of the flat roof between the columns

JUNCTION, ON CITY AND SOUTH LONDON RAILWAY

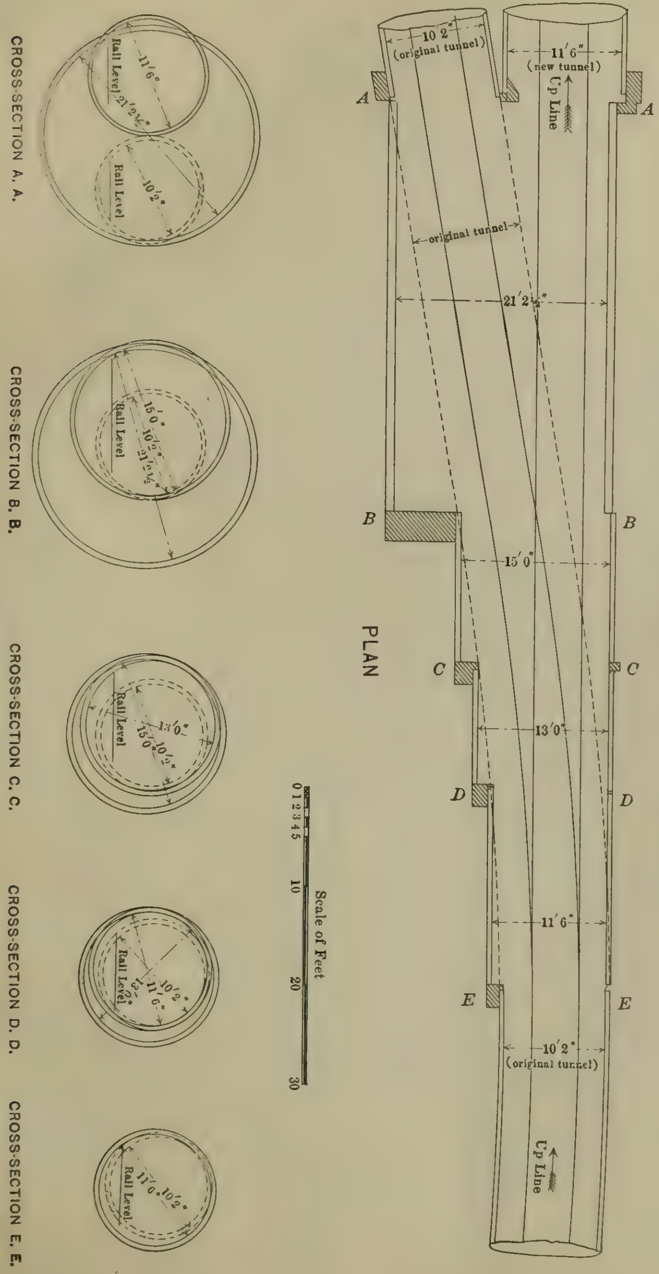


Fig 1.

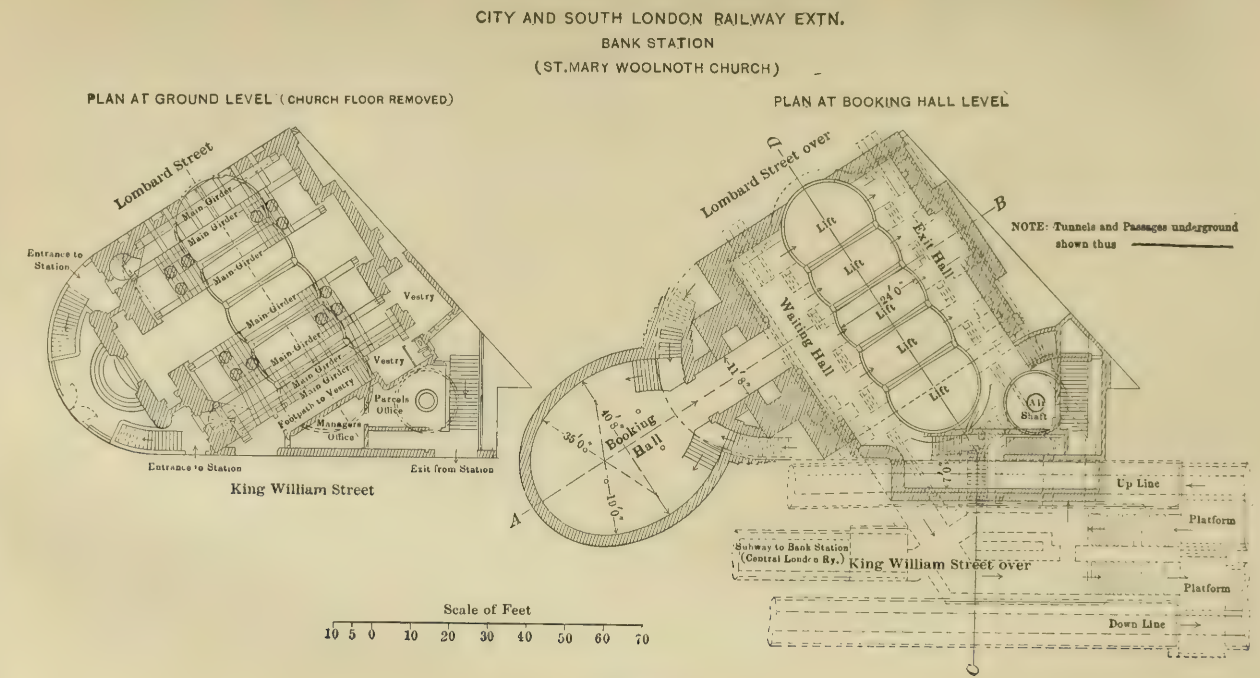

CITY AND SOUTH LONDON RAILWAY EXTN.
BANK STATION
(ST. MARY WOOLNOTH CHURCH)
PLAN AT GROUND LEVEL (CHURCH FLOOR REMOVED)
Lombard Street
Main Girder
Main Girder
Main Girder
Main Girder
Main Girder
Main Girder
Main Girder
Entrance to Station
Vestry
Vestry
Footpath to Vestry
Parcels Office
Managers Office
Entrance to Station
Exit from Station
King William Street
PLAN AT BOOKING HALL LEVEL
Lombard Street over
D
B
NOTE: Tunnels and Passages underground shown thus
Lift
Lift
Lift
Lift
Lift
24′ 0″
Exit Hall
Waiting Hall
11′ 8″
40′ 8″
35′ 0″
10′ 0″
Booking Hall
A
Air Shaft
7′ 0″
Up Line
Platform
Subway to Bank Station (Central London Ry.)
King William Street over
Platform
Down Line
C
Scale of Feet
10 5 0 10 20 30 40 50 60 70

FIG. 2

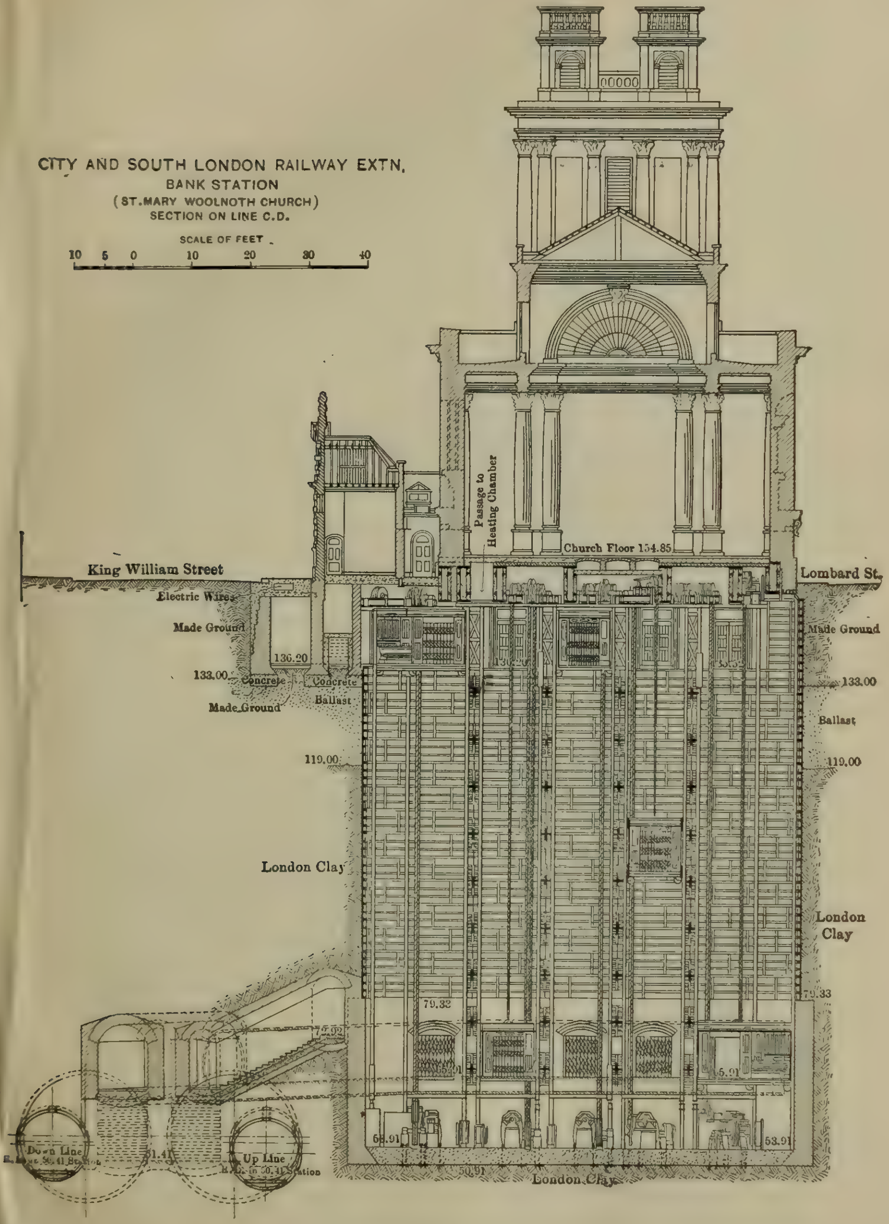

CITY AND SOUTH LONDON RAILWAY EXTN.
BANK STATION
(ST. MARY WOOLNOTH CHURCH)
SECTION ON LINE C.D.
SCALE OF FEET
10 5 0 10 20 30 40
Passage to Heating Chamber
Church Floor 154.85
King William Street
Lombard St.
Electric Wires
Made Ground
136.20
133.00
Concrete
Concrete
Ballast
Made Ground
Made Ground
133.00
Ballast
119.00
119.00
London Clay
London Clay
79.33
79.33
72.92
65.91
65.91
65.91
53.91
50.91
London Clay
Down Line
R. L. in 50.41 Station
51.41
Up Line
R. L. in 50.41 Station

FIG. 3.

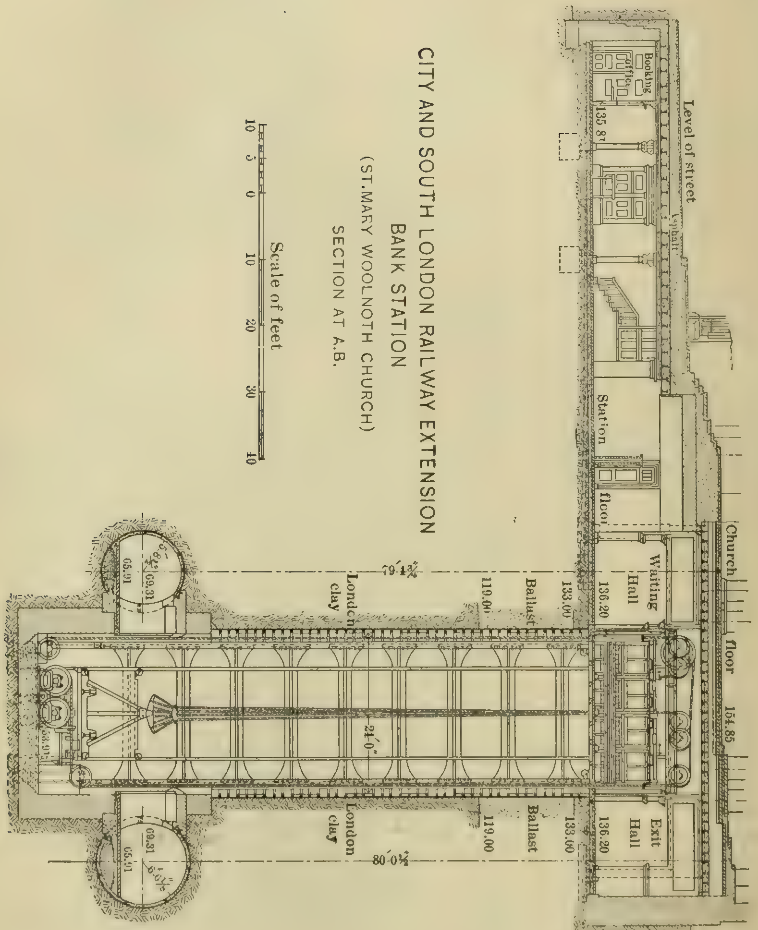

CITY AND SOUTH LONDON RAILWAY EXTENSION
BANK STATION
(ST. MARY WOOLNOTH CHURCH)
SECTION AT A.B.
Scale of feet
10 5 0 10 20 30 40
Level of street
Asphalt
Booking office
135.87
Station floor
Church floor
154.85
Waiting Hall
Exit Hall
136.20
133.00
Ballast
119.00
London clay
79′ 4¾″
80′ 0½″
24′ 0″
69.31
65.91
38.91

FIG. 4.

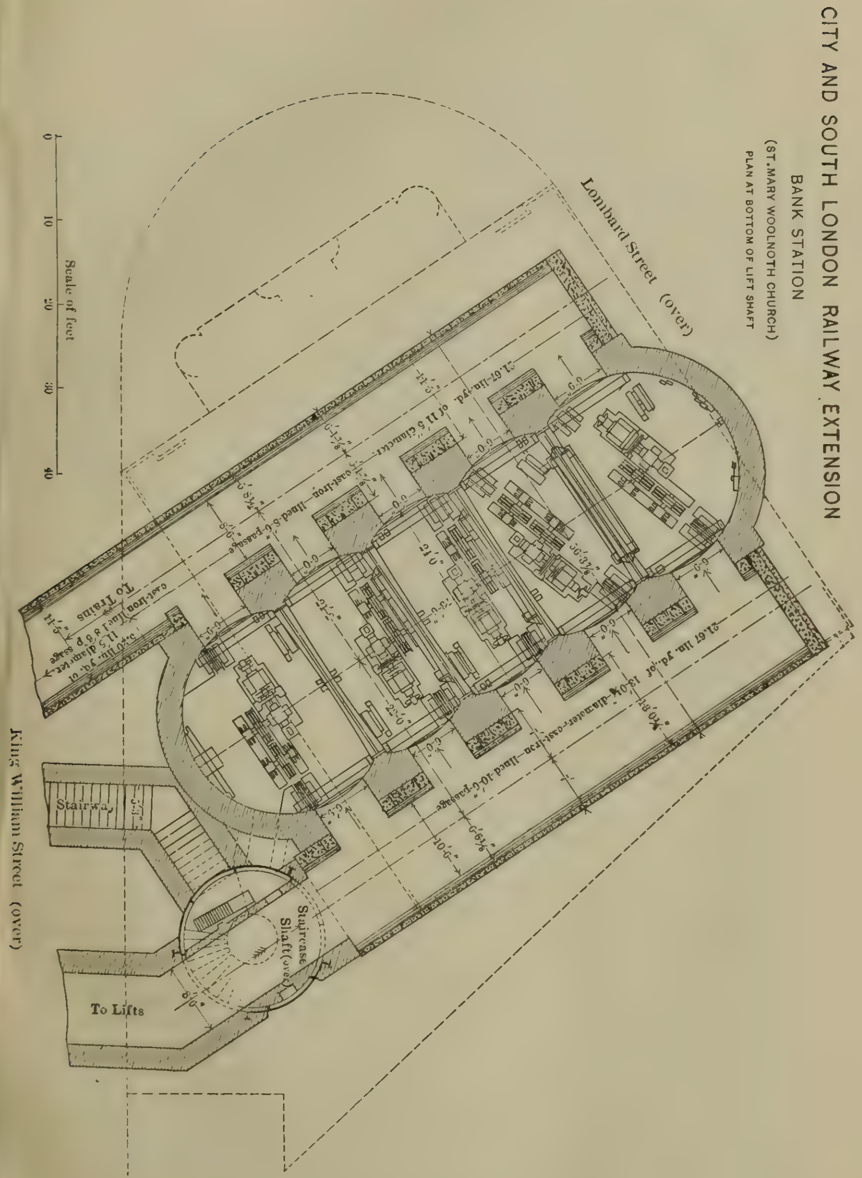

CITY AND SOUTH LONDON RAILWAY EXTENSION
BANK STATION
(ST. MARY WOOLNOTH CHURCH)
PLAN AT BOTTOM OF LIFT SHAFT
Lombard Street (over)
King William Street (over)
Scale of feet
0
10
20
30
40
To Trains
Stairway
Staircase Shaft (over)
To Lifts
21.67 lin. yd. of 11 6 diameter
21.67 lin. yd. of 13.0½ diameter cast-iron-lined 10-6 passage
cast-iron-lined 8-0 passage
5.0 lin. yd. of 11.5 diameter cast-iron lined 8-6 passage
21'-0"
22'-0"
30'-3⅞"
8'-0"
10'-0"

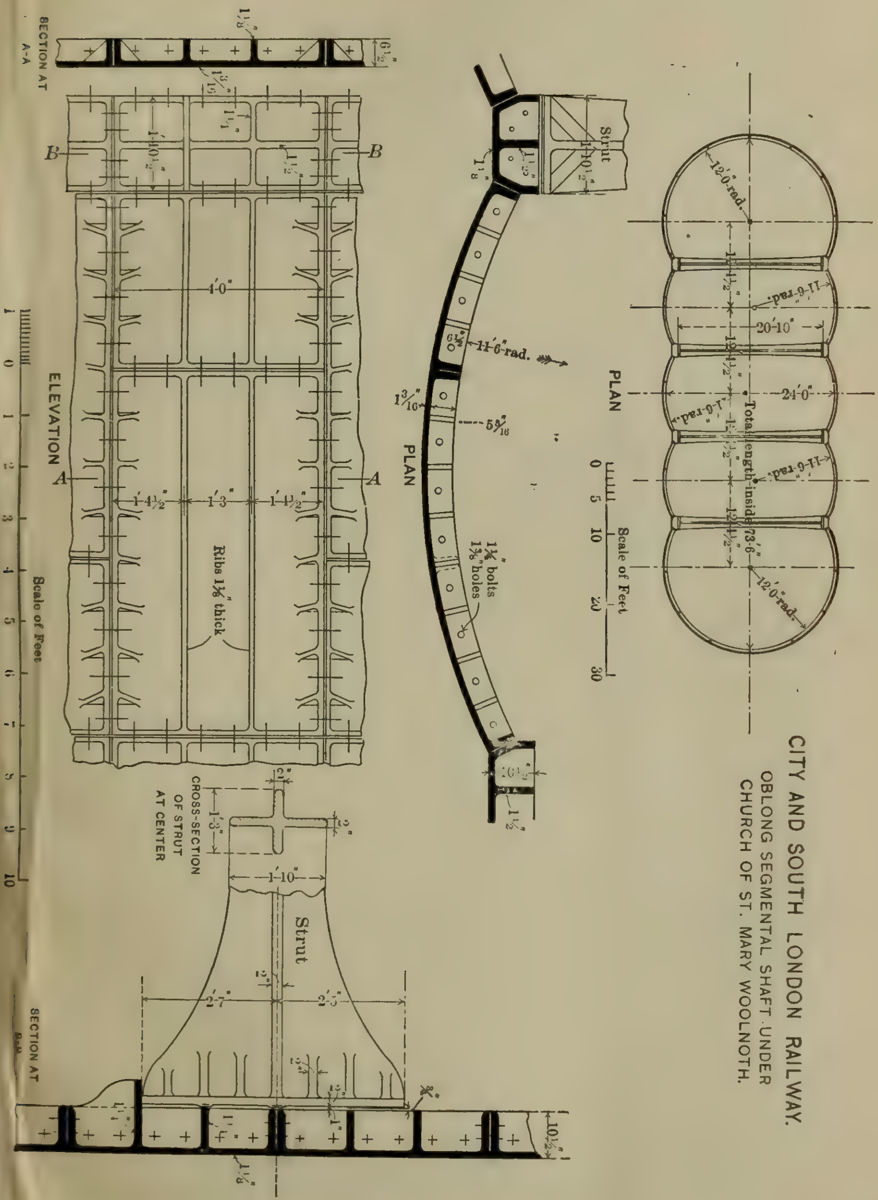
FIG. 5.

and the outside walls. They were built on brick piers, the foundations of which were carried down a considerable distance below the church floor.

The problem of transferring the stone columns to supports, which would leave the ground below free for sinking the oblong lift shaft, etc., was solved as follows: A reference to Fig. 2 will show that four main girders were used for this purpose, two for each two groups of columns. The girders were 52 ft. 6 in. long and 5 ft. 6 in. deep, and were fixed on wrought-steel stanchions carried on massive bed-plates (indicated in the plan at booking hall level, Fig. 2, by dotted lines), and were placed so that they could be put in position without interfering with the old brick piers.

When the main girders were fixed, the column bases were pierced for the cross-needles, and it was hoped that nothing more would be needed to support them effectively. The interior of the bases, however, proved to be of such inferior work that a sheeting of steel joists had to be placed over the needles to bind the whole together, and to distribute the weight equally upon the needle girders. It was necessary, of course, to make provision for taking up the deflection of the main girders when the weight should be thrown upon them, and this was done by driving planed-steel wedges in between the main girders and the needles as the brick piers were cut away underneath. This was completely successful in avoiding even the least crack in the superstructure, or in the ornamental plastering on the ceiling of the church.

Having thus dealt with the columns carrying the roof, the support for the wall next to King William Street was proceeded with. Two main girders, 50 ft. 7 in. by 5 ft. 6 in., were used for this purpose. The inner one was first built alongside the wall. The wall was then pierced at intervals of about 5 ft., and needle girders were placed through the holes, their other ends resting on, and tied down to, one of the main girders for supporting the columns. A sufficient part of the inside of the wall was then cut away to allow of the girder being placed in position, and for a 14-in. blue-brick wall carrying short lengths of steel bearers, which were wedged up tight to the needle girders. The object of the brick wall was to reduce the overhang of the needles when the outer part of the wall should be cut away, as no reliance could be placed upon the old stonework.



CITY AND SOUTH LONDON RAILWAY.
OBLONG SEGMENTAL SHAFT UNDER
CHURCH OF ST. MARY WOOLNOTH.

FIG. 6.

After the inside girder had been fixed securely upon the end supports, steel wedges and packings were inserted between the top of the girder and the needles, the wedges being driven up tight to ensure that the whole of the weight was being carried on the girder, and the blue-brick wall, previously referred to (as the girder was designed to carry permanently only half the wall, it was assisted by timber packings below). After the wall had been pinned up above the girder, and everything had been made solid by grouting, under pneumatic pressure, the work of fixing the outer girder was comparatively simple.

The outer half of the wall was cut away below the needles, and the girder, which, meanwhile, had been built alongside, was moved into position. The whole of the weight, about 350 tons, was then taken by the two girders, and, as the timber packings below the inside girder were removed, wedges were driven in between the needles and girders to take up the deflection, as in the case of the columns.

The same method could not be used for supporting the wall on the Lombard Street side, as it was not possible to carry out any work in that street. One main girder, therefore, was designed to carry the whole weight, but as it could not, with safety, be placed sufficiently far under the wall to do this, suspended needles were attached to carry the outer part of the wall, the tail ends being tied down to one of the girders supporting the roof columns. The same method of carrying out the work was followed as in the case of the King William Street wall. Needle girders were fixed just below the level of the church floor, under cover of which needles the wall was cut away to allow the large girder to be placed in position. After the wall had been pinned up above the girder, the suspended needles were fixed one by one, and the intervening masonry was held up by steel cross-joists placed over the needles.

The deflection of the girders was, in every case, taken up by a system of folding steel wedges, which were tightened up as the old foundations were cut away and the superincumbent weight was taken by the girders. Cement grouting under air pressure was largely used, especially in filling up any interstices between the girders, stanchions, etc., and in the old masonry.

The girders were supported on steel stanchions, resting on large bed-plates formed of steel joists, and plates laid on a bed of con-

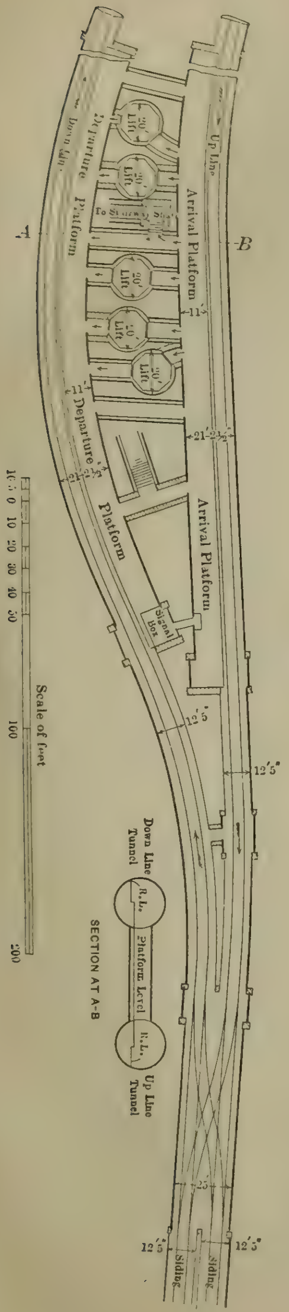

Down Line
Departure Platform
Up Line
Arrival Platform
20' Lift
To Stairway
11'
21'
Departure Platform
Arrival Platform
Signal Box
12'5"
A
B
Siding
Siding
Down Line Tunnel
Up Line Tunnel
R.L.
Platform Level
SECTION AT A-B
Scale of feet
10 5 0 10 20 30 40 50 100 200

FIG. 8.

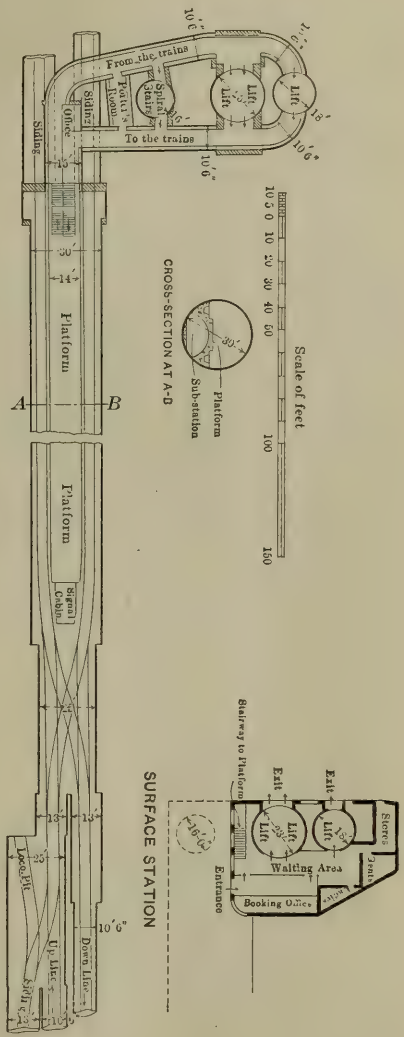

From the trains
To the trains
Lift
Spiral Stairs
Porter's Room
Siding
Office
Siding
10'6"
18'
15'
30'
14'
Platform
A
B
Platform
Signal Cabin
24'
13'
23'
Loco. Pit
Up Line
Down Line
Siding
10'6"
CROSS-SECTION AT A-B
Platform
Sub-station
Scale of feet
10 5 0 10 20 30 40 50 100 150
SURFACE STATION
Stairway to Platform
Exit
Exit
Stores
Lift
Waiting Area
Booking Office
Entrance
16'0"

FIG. 7.

crete of a minimum thickness of 3 ft. All box girders, stanchions, etc., were filled solid, and cased in breeze concrete, to guard against deterioration through any neglect of painting, which so often takes place.

Fig. 3 is a section taken on Line *C-D* (Fig. 2), and shows the main girders and needles in position under the walls and columns. Fig. 4 is a section taken on Line *A-B* (Fig. 2), through the center line of the booking hall.

The work of supporting and underpinning the church occupied just twelve months. Only a small portion could be taken in hand at one time, and all the girders had to be put together inside the building in a very limited space.

Of course, very great care was taken during the carrying out of every operation, and it is satisfactory to record that not a single crack occurred in the edifice; it is safe to say that the building is now considerably stronger than before.

The supporting of the church being completed, the next work undertaken was the sinking of the lift shaft. The form of this shaft in plan is indicated on Fig. 2, and its inside dimensions are 73 ft. 6 in. by 24 ft. 0 in. It is formed of a series of segments, cast-iron struts being placed every 8 ft. in depth, at the intersection of the segments. The upper 52 ft. is lined with cast-iron plates and the lower 25 ft. with brickwork (Fig. 4), the brickwork portion being put in to simplify the construction of the lift openings leading into the passages alongside (Fig. 5). Details of the cast-iron lining are shown on Fig. 6.

Five lifts are placed in the shaft; the two end cages are capable of carrying more than 100 passengers each, and the others about 85 each. They are worked electrically, the winding gear being placed in the bottom of the shaft on account of the limited headway under the church floor. The lift gears are shown on Figs. 3, 4 and 5.

The tunnels and underground passages are indicated in Fig. 2 by lines of dots and dashes.

The present termini of the railway are at Clapham Common and Islington, and it is the intention to make a further extension from the latter to Euston (the terminus of the London and North Western Railway), with an intermediate station at King's Cross and St. Pancras, the termini of the Great Northern Railway and the Midland Railway.

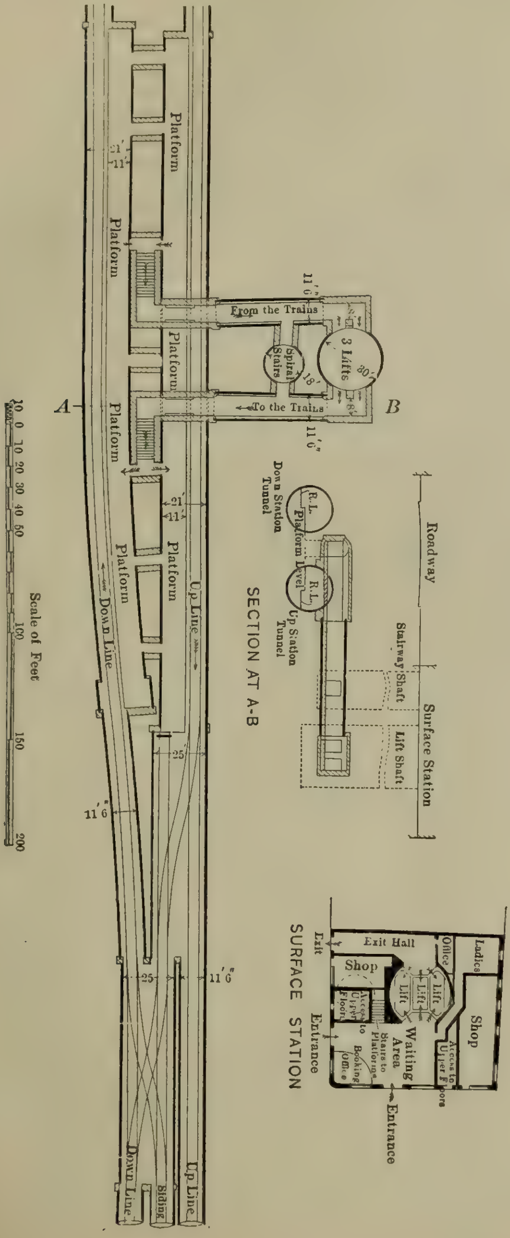

Platform
Platform
Platform
Platform
Platform
Platform
21'
11'
21'
11'
From the Trains
To the Trains
Spiral Stairs
3 Lifts
30'
18'
8'
11' 6"
11' 6"
A
B
Up Line
Down Line
25'
11' 6"
25
11' 6"
Down Line
Siding
Up Line
Scale of Feet
10 0 10 20 30 40 50 100 150 200
SECTION AT A-B
Roadway
Stairway Shaft
Surface Station
Lift Shaft
R.L.
R.L.
Platform Level
Down Station Tunnel
Up Station Tunnel
SURFACE STATION
Exit Hall
Exit
Office
Ladies
Shop
Shop
Lift
Lift
Lift
Access to Upper Floors
Access to Upper Floors
Waiting Area
Stairs to Platforms
Booking Office
Entrance
Entrance

FIG. 9.

This somewhat detailed description of the work under St. Mary Woolnoth Church is not, of course, typical of tube-railway construction, but is interesting as a method of overcoming a special difficulty, and it is not unlikely that the upholding of heavy buildings for station purposes may become a more frequent necessity in future railway development.

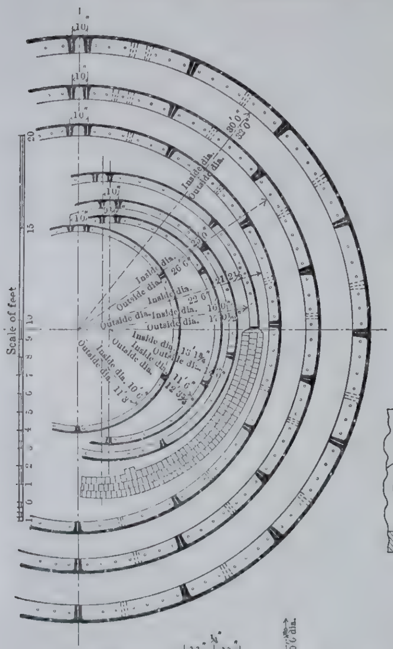
The construction of all the remaining tube railways in London has been, and is being, carried out on practically the same lines as that of the City and South London Railway, with, of course, modifications to suit special circumstances.

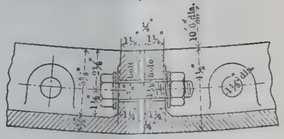
The lengths of stations, size of tunnels, etc., have been increased to meet the requirements of larger rolling stock, necessitated on such lines as the Central London Railway, where the density of traffic is naturally greater than on the South London Railway. In order to condense matters as far as possible, and to avoid repetitions, the writers have prepared a set of illustrations to accompany this paper, which will probably be of more value and interest than any detailed description of other railways, the various routes of which are shown on Plate XXX.

Plate XXXII shows the details of the castings for the 10 ft. 6 in., 11 ft. 6 in., 13 ft. 1¾ in., 16 ft. 0 in., 21 ft. 2½ in., 25 ft. 0 in. and 30 ft. 0 in. tunnels. The 10 ft. 6 in. is the City and South London Main Line tunnel lining. The 11 ft. 6 in. and 11 ft. 8¼ in. is the main line tunnel lining for practically all other London tube railways, the horizontal or radial joint, in some cases, being planed. The 16 ft. 0 in. is the main line tunnel lining for the Great Northern and City Railway, with brick invert. The 13 ft. 1¾ in. is a usual type of lining for sidings. The 21 ft. 2½ in. is the lining as used for station tunnels. The 25 ft. 0 in. is the lining as used for cross-over roads at terminal stations, and also for intermediate stations where sidings are required. The 30 ft. 0 in. is the lining used for terminal stations with island platforms.

Plate XXXIII shows the details of the castings for the 16, 18, 20, 23 and 30-ft. shafts. The 16 and 18-ft. castings are the type usually adopted for the spiral stairway shafts, which are required by the Board of Trade as a means of entrance and exit in the case of the lifts failing. The 20-ft. is the type used for lift shafts when required to contain only one large lift. The 23-ft. is the type used for lift

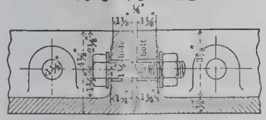
NOTE: The Rings of the 10′6″, 11′6″, 13′1¾″ and 16′0″ tunnels are 1′8″ long.
The Rings of the 21′2½″, 25′0″ and 30′0″ tunnels are 1′6″ long.
All holes in circumferential flanges spaced for segments to break joint.



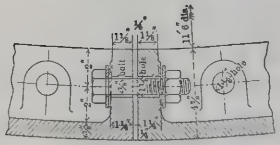


HORIZONTAL JOINT

10′6″ TUNNEL

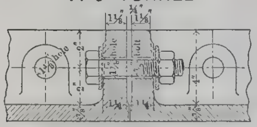


CIRCUMFERENTIAL JOINT

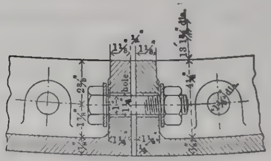


HORIZONTAL JOINT

11′6″ TUNNEL

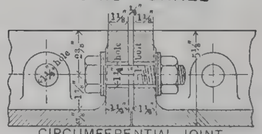


CIRCUMFERENTIAL JOINT



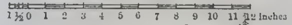
HORIZONTAL JOINT

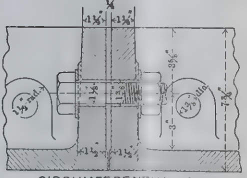
13′1¾″ TUNNEL



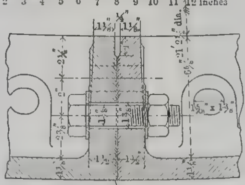
CIRCUMFERENTIAL JOINT

Scale for details





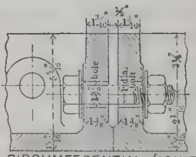
CIRCUMFERENTIAL JOINT



HORIZONTAL JOINT

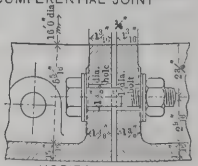
Machined faces

21′ 2½″ TUNNEL

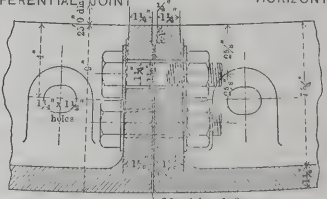


CIRCUMFERENTIAL JOINT

16 FT. TUNNEL

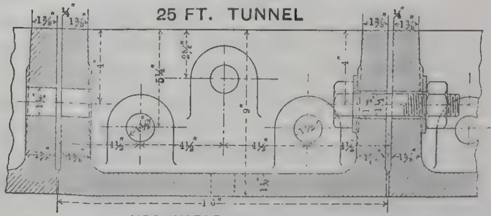


HORIZONTAL JOINT

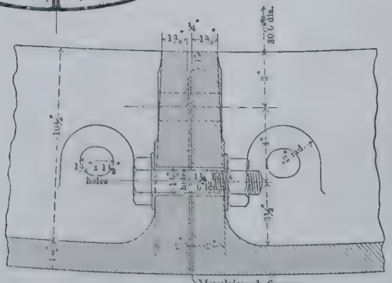


HORIZONTAL JOINT

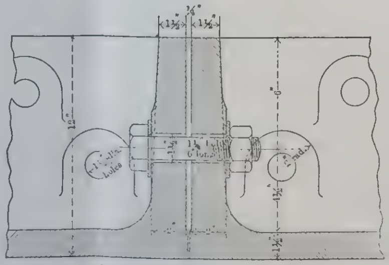
25 FT. TUNNEL



CIRCUMFERENTIAL JOINT



HORIZONTAL JOINT



CIRCUMFERENTIAL JOINT

30 FT. TUNNEL

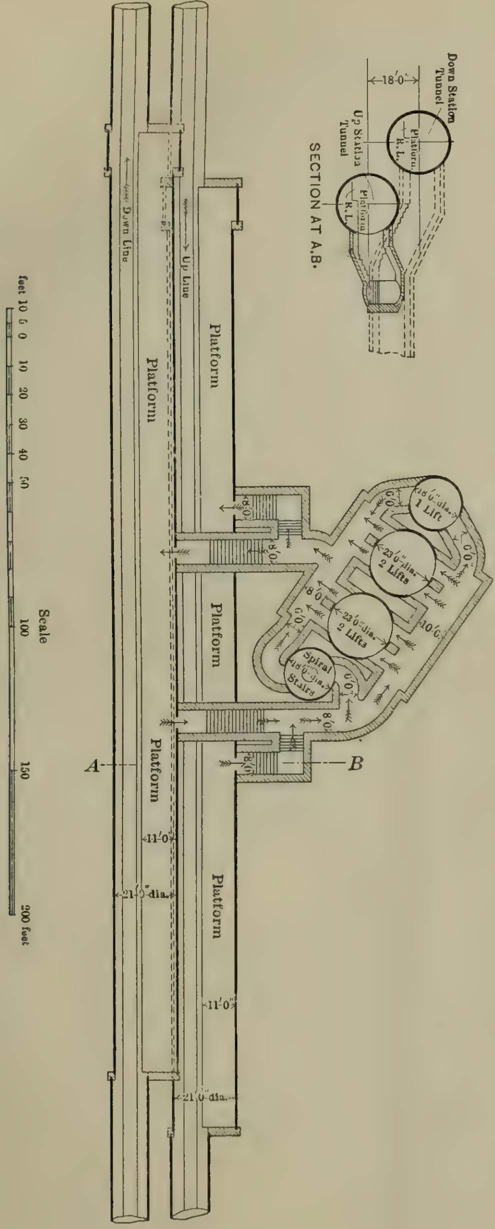

Down Station Tunnel
Up Station Tunnel
Platform
R.L.
18'0"
SECTION AT A.B.
Down Line
Up Line
Platform
8'0"
18'0" dia. 1 Lift
23'0" dia. 2 Lifts
Spiral Stairs 18'0" dia.
6'0"
10'0"
11'0"
21'0" dia.
A
B
Scale
feet 10 5 0 10 20 30 40 50 100 150 200 feet

FIG. 10.

shafts when containing two lifts. The 30-ft. is the type used for lift shafts containing three lifts. The cutting edge, as shown, is used only in sinking the shafts through very bad ground containing water. The usual method of sinking these iron-lined shafts is by underpinning.

Fig. 7 is a typical drawing of a terminal station of 30 ft. diameter, with island platform, 14 ft. 0 in. wide, and with a cross-over in front of the station. This type of station gives excellent results, both as regards cost of construction and working, where short light trains are used, and is adopted on the City and South London Railway; but with trains of 300 ft. and more in length, it is not satisfactory, and limits the service to 3½ min., owing partly to the stricter signaling arrangements required by the Board of Trade.

Fig. 8 is a typical drawing of a terminal station with up and down platforms in separate 21 ft. 2½ in. tunnels, and the cross-over with sidings beyond the station. In practice, this has proved the best scheme, and allows for a train service of 1½ min. when properly organised. In this case the lift shafts are shown between the station tunnels, as at the Bank Station on the Central London Railway. It is an ideal arrangement for tube-railway working, but can be carried out only where there is space available for the surface station, booking hall, etc., to be constructed immediately above the running line.

Fig. 9 is a typical drawing of an intermediate station, with cross-over road and siding. Where the street is wide enough for the two 21 ft. 2½ in. platform tunnels to be used on the same level with stairways in between, this is a simple arrangement, and can be worked with a small staff.

Fig. 10 is a typical drawing of an intermediate station where the roadway is too narrow for the platforms to be on the same level. The method of tube construction is well adapted to conditions of this kind; the tunnels can be put in any position relative to one another without difficulty.

Fig. 11 shows the various types of permanent way used on the existing tube railways, and proposed for those at present under construction.

Though the design and method of constructing the tubes, etc., as in the foregoing illustrations, is still practically identical with

PLATE XXXIII. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
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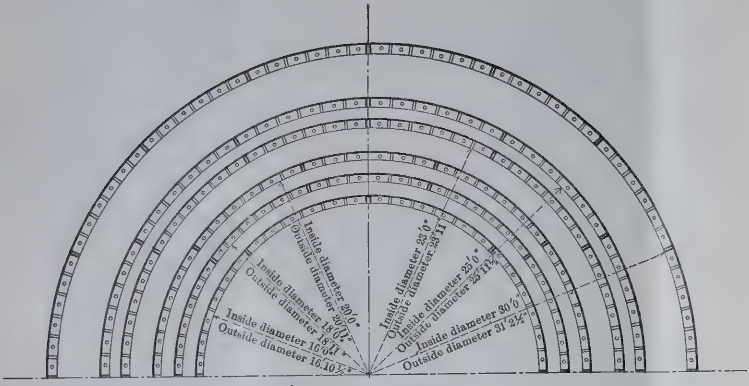
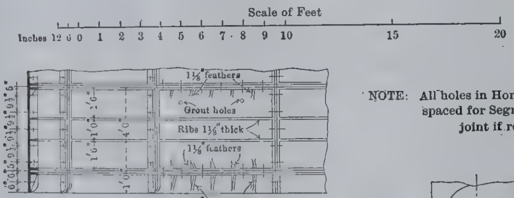
MOTT AND HAY ON
UNDERGROUND RAILWAYS.

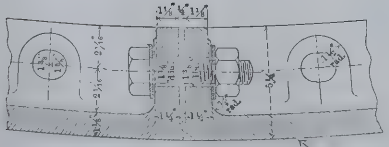


HALF PLAN OF SHAFTS.

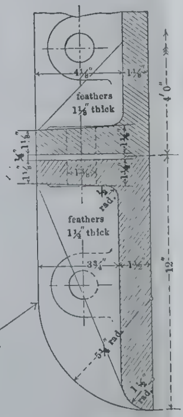


PART ELEVATION OF SHAFT.

NOTE: All holes in Horizontal Flanges spaced for Segments to break joint if required.

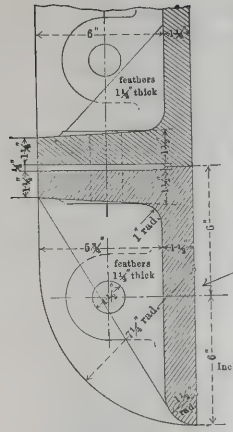


VERTICAL JOINT.

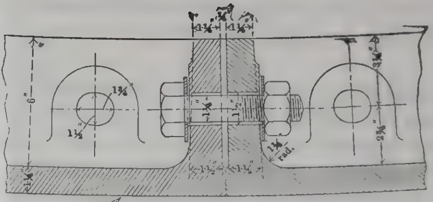


HORIZONTAL JOINT AND CUTTER.

16-FT. SHAFT.

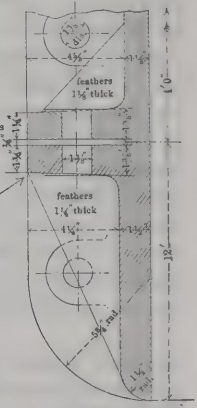


HORIZONTAL JOINT AND CUTTER.

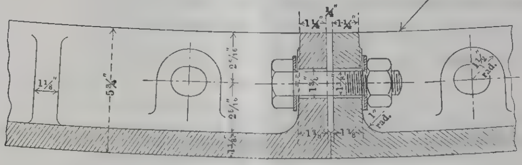


VERTICAL JOINT.

30-FT. SHAFT.



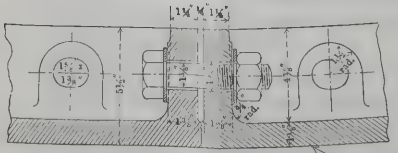
Scale for Details
Inch 1 ½ 0 1 2 3 4 5 6 7 8 9 10 Inches



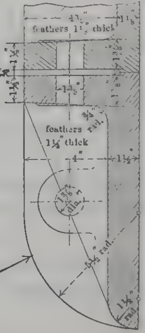
VERTICAL JOINT.

HORIZONTAL JOINT AND CUTTER.

25-FT. SHAFT.



VERTICAL JOINT.



18, 20 AND 23-FT. SHAFTS.

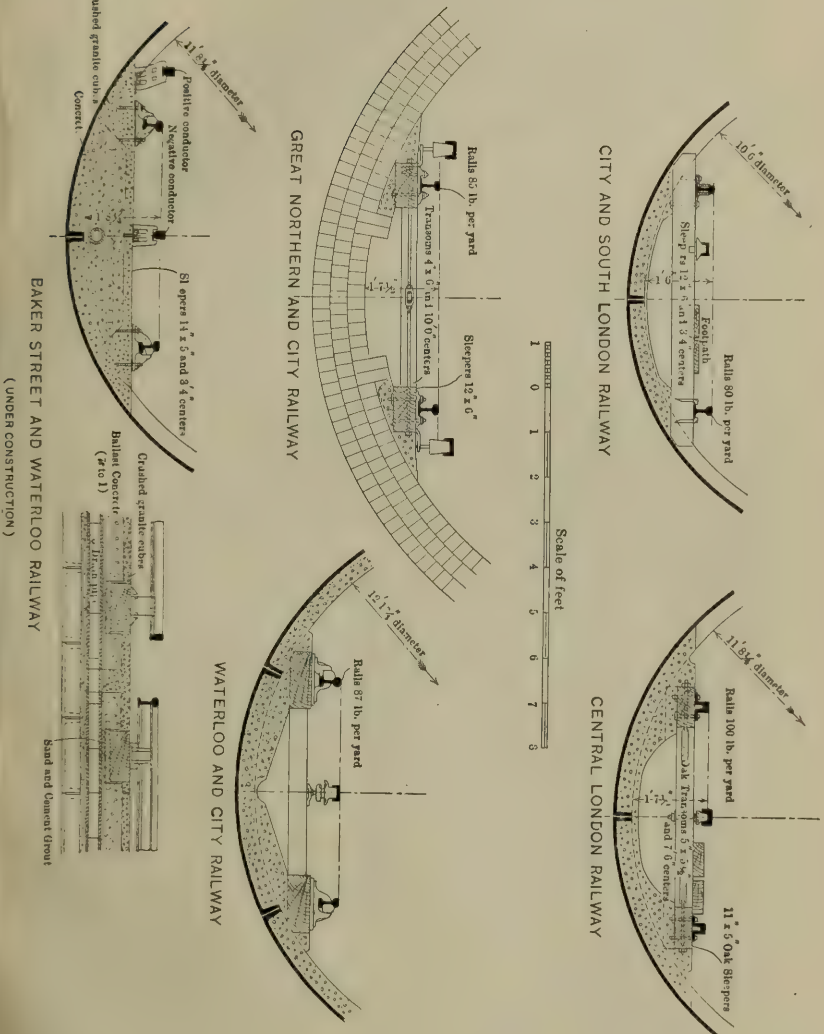

10' 6" diameter
Sleepers 12" x 6" and 1' 3' 4" centers
1' 6"
Footpath
Rails 80 lb. per yard
CITY AND SOUTH LONDON RAILWAY
11' 8¼" diameter
Rails 100 lb. per yard
Oak Transoms 5" x 5⅛" and 7' 6" centers
1' 7½"
11" x 5" Oak Sleepers
CENTRAL LONDON RAILWAY
Scale of feet
1 0 1 2 3 4 5 6 7 8
Rails 85 lb. per yard
Transoms 4" x 6" and 10' 0" centers
1' 7½"
Sleepers 12" x 6"
GREAT NORTHERN AND CITY RAILWAY
12' 1½" diameter
Rails 87 lb. per yard
WATERLOO AND CITY RAILWAY
11' 8¼" diameter
Positive conductor
Negative conductor
Sleepers 14" x 5" and 3' 4" centers
Crushed granite cubes
Concrete
Crushed granite cubes
Ballast Concrete (8 to 1)
Sand and Cement Grout
BAKER STREET AND WATERLOO RAILWAY
(UNDER CONSTRUCTION)

FIG. 11.

the original proposals of Mr. Greathead in 1885, an advance has been made in the rate of progress owing to the successful use of a boring machine designed by Mr. John Price, the contractor for various tube railways, which deserves some description.

The machine (Plate XXXIV, Figs. 1 and 2) is a combination of an ordinary "Greathead shield" and an excavator. The only alteration to the shield is that in the diaphragm plate a circular instead of a square opening is made of sufficient size to admit the head of the excavator.

The excavator itself consists of six radial arms (forming a cutter head) carried on a center shaft, which is attached to the shield by transverse girders. The radial arms, which carry the cutters, are supported at their extremities by an outer annular ring, to which are attached the buckets for picking up the excavation from the bottom of the shield as it falls from the cutters. The cutter head and buckets are driven by a 50-h-p. tramway motor.

The excavated material is discharged from the buckets upon a belt conveyor, and delivered automatically into trucks about 50 ft. from the working face, and no handling is required.

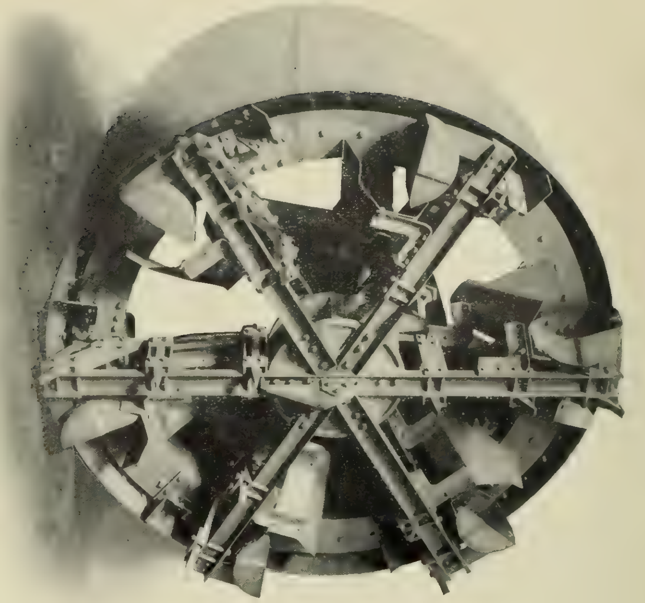
The cutters are kept up to their work by the hydraulic rams on the shield.

Excellent progress is being made with these machines, and 16 ft. 8 in. of 11 ft. 6 in. iron-lined tunnel have been completed in one ten-hour shift. This, of course, is exceptional, the average rate of progress being about 140 ft. per week at each face, which is double the average rate by the ordinary method of construction.

GLASGOW DISTRICT SUBWAY.

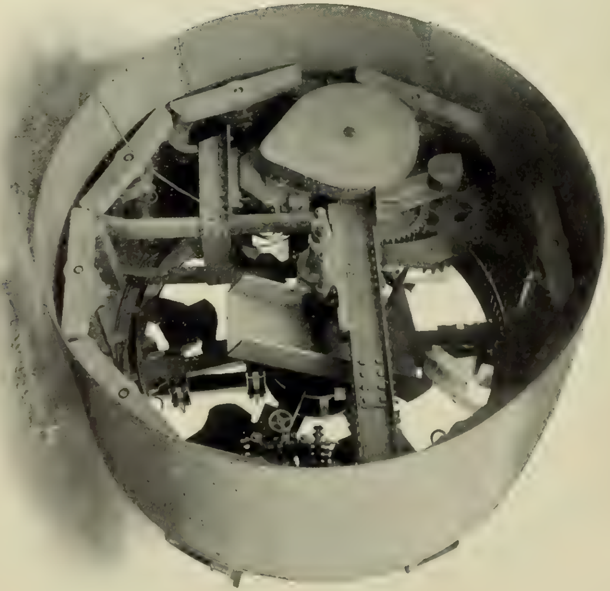
This is the only example in Great Britain of combined "shallow subway" and "deep-level tube" construction.

The line is a circular one, and connects the western suburbs of Glasgow with the center of the city. The total length is about 6½ miles, and the up and down lines are in separate tunnels, 11 ft. internal diameter, the section varying according to the nature of the ground and the depth below the surface. Where the depth to formation level is not more than 30 ft., and the surface is unoccupied, the ordinary cut-and-cover method of construction was adopted (Plate XXXI). Iron-lined tunnels, driven under compressed air, were used



FRONT VIEW.

PRICE'S TUNNELING MACHINE.



BACK VIEW.

where the strata were water-bearing, or the surface was occupied by buildings of an important character. Where the ground was dry and the buildings were of a poor character, circular brick tunnels, with concrete inverts, were substituted in order to save expense, but when the extra excavation, the much slower rate of progress and the damaged property (even when not serious) are taken into consideration, it is doubtful whether the saving amounts to anything appreciable. There are fifteen stations, about ½ mile apart. The stations are 28 ft. wide and 150 ft. long, with island platforms, 10 ft. wide, which, for any considerable traffic, is too narrow. The gradients, in certain cases, are rather severe, especially at the two river crossings, where the grade is 1 in 20, but, as the line is worked by cable haulage, it is not of much consequence.

One of the chief interests of this line is an example of shallow subway construction, which has been much under discussion lately, for London. The iron-lined portion is practically the same as that adopted for all tube railways, except that the radial, as well as the circumferential joints, have a fillet at the back projecting about ¼ in. (Plate XXXI); the advantage of this is not apparent, and it increases the likelihood of the distortion of the tunnel. In the opinion of the writers, the radial joint should have no fillet, and be either unplaned, with a thin wood packing, or planed, without packing. The planing adds slightly to the cost, and is only necessary in tunnels of large diameter. The only other case, of which the writers are aware, of an iron tunnel with a back fillet to a radial joint, is also in Glasgow, on the harbour tunnel.

Future Development.

With the introduction of shield-driven tube railways, it was hoped that the traffic problem of London was, to some degree, solved, and that the adoption of this method of construction would enable a reasonable dividend to be paid upon the capital expended. Unfortunately, this has not turned out to be the case. The cost of construction has increased very rapidly, and the restrictions and obligations put upon the various companies by Parliament, at the instance of the local authorities and the London County Council, prevent anything but a meager return to the shareholders. The problem has become acute, and a Royal Commission has been sitting in London for the past year and a half to consider the traffic question as a whole, but, unless some facilities can be given in the way of free way leave under property, and the construction without charge of stations in the streets, as in Paris, it is doubtful, when the lines at present under construction are completed, whether any further railways, either in the form of shallow subways or as tubes, will be constructed in London, at any rate, by private enterprise.

If the necessary facilities are granted, however, and the construction of railways is recommended, as a result of the investigations of this Royal Commission, the writers are of the opinion that the most practical scheme is a system of shallow subway construction outside the congested areas combined with tubes in the central districts.

The writers have worked out numerous proposals for railways through London along the various main lines of traffic, and on approaching the central area the ordinary cut-and-cover or shallow construction becomes impossible, not only on account of the difficulty in dealing with the innumerable gas, water and high-pressure hydraulic pipes, pneumatic tubes, electric lighting and telephone cables, the diversion of sewers and the interference with existing cellars (which in many cases stretch right across the streets), but mainly from the fact that the ground is already occupied near the surface by existing railways, canals and large main drainage sewers, which cannot be diverted, and under which any new shallow railways must dip. These obstructions cross the main routes at such frequent intervals that, if reasonable gradients are to be maintained, new lines must of necessity be constructed at a considerable depth, which calls for tube construction with stations served by lifts. This is altogether apart from the great dislocation of traffic necessitated by cut-and-cover work, and the opposition to this in London would be so great that it is highly improbable that Parliament would sanction, along such routes as, say, Fleet Street, or the Strand, schemes which require for their construction the wholesale occupation of streets and dislocation of traffic, to which New York City has submitted during the construction of its "rapid transit" system.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,
1904.

Paper No. 90.

UNDERGROUND RAILWAYS.

UNDERGROUND RAILWAYS IN THE UNITED STATES.

By William Barclay Parsons, M. Am. Soc. C. E.

In the consideration of American practise in underground railway construction, the term underground railway will be limited to cover sub-surface railways in cities intended primarily for local transit, as differentiated from sub-surface railways forming parts of through lines. The latter railways, in their design and construction, are more properly considered under "Tunneling."

In the United States there have been constructed or put under construction only three underground railways for local transit. While it is difficult to establish rules of practise from three examples, nevertheless, as these lines differ in many respects, in feature of design and construction, from similar lines in Europe, these different characteristics can be set down as determining the tendency of American practise. The three railways referred to, in order of their construction, are as follows:

	Miles Constructed.	Miles Under Construction.	Total.
Boston	3.1	1.2	4.3
New York	15.5	3.5	19.0
Philadelphia	....	2.0	....

In addition to the above mileage, which is exclusive of elevated or viaduct extensions, very extensive additions are being considered for New York, and some additions in both Boston and Philadelphia. These extensions will be constructed in accordance with the same standards as the lines already in operation.

The characteristic features of these railways, and in which they differ from European practise in similar railways, are:

1.—Near approach to the street surface;

2.—The use of steel beams in walls as well as in roofs;

3.—Simplicity of design in steel structure;

4.—The use of concrete instead of brick or stone masonry;

5.—The use of reinforced concrete;

6.—The addition of extra tracks for express or special service;

7.—A freedom in design whereby the general type of structure is changed to meet local requirements.

These seven characteristics will be considered *seriatim:*

1.—Near Approach to the Street Surface.—The enormous travel already existing on the surface railways in American cities lead the designers of sub-surface railways not only to discard at the very outset any consideration of deep railways requiring mechanical means of transferring passengers from the pavement to the platform level or *vice versa,* but to bring these two levels as closely together as possible, even at great cost and interference with other sub-surface structures.

The sub-surface structures existing in the streets of American cities are: Sewers, at a depth of from 12 to 15 ft., ranging ordinarily in size from 12-in. vitrified pipe to egg-shaped sewers in brick 4 ft. by 2 ft. 8 in., or 4-ft. circular, or, occasionally, in the case of large trunk sewers, to a diameter of 8 or 10 ft.; water or gas mains from 3 to 48 in. in diameter; electrical conduits for power, light, telegraph, and telephone wires; steam pipes; pneumatic tubes, and, in New York, the sub-conduit of the surface electric railways.

It is the presence of these structures that regulates the height to which the roof of the railway can be brought. As a general thing, the sewers and the water pipes alone are the property of the municipality, the other structures belonging to private corporations, who, however, cannot object to the readjustment of their mains, provided the service can be maintained properly.

PLATE XXXV. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
PARSONS ON
UNDERGROUND RAILWAYS.

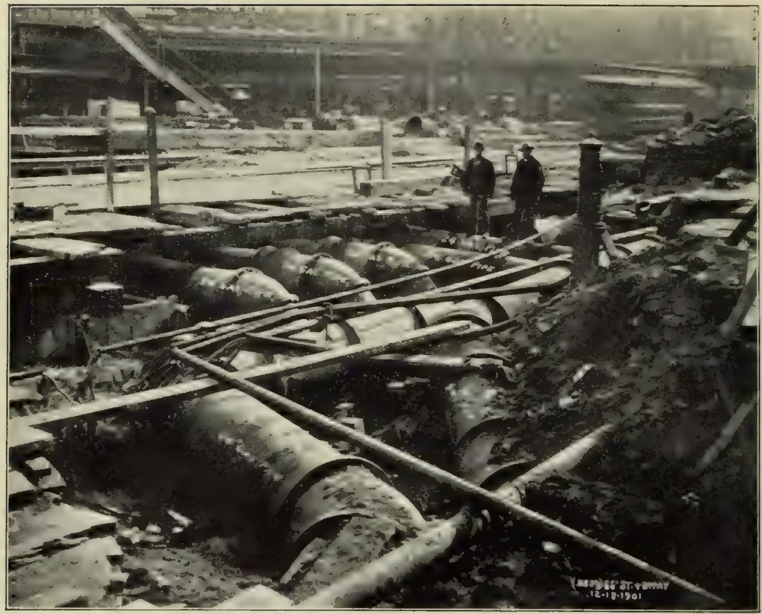


FIG. 1.—SUB-DIVISION OF LARGE GAS MAINS, AT SIXTY-SIXTH STREET AND BROADWAY, N. Y.

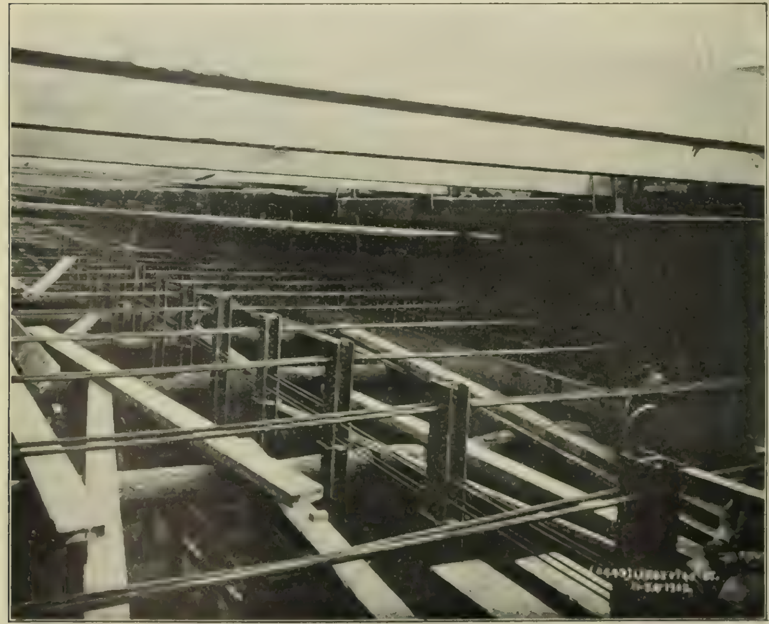


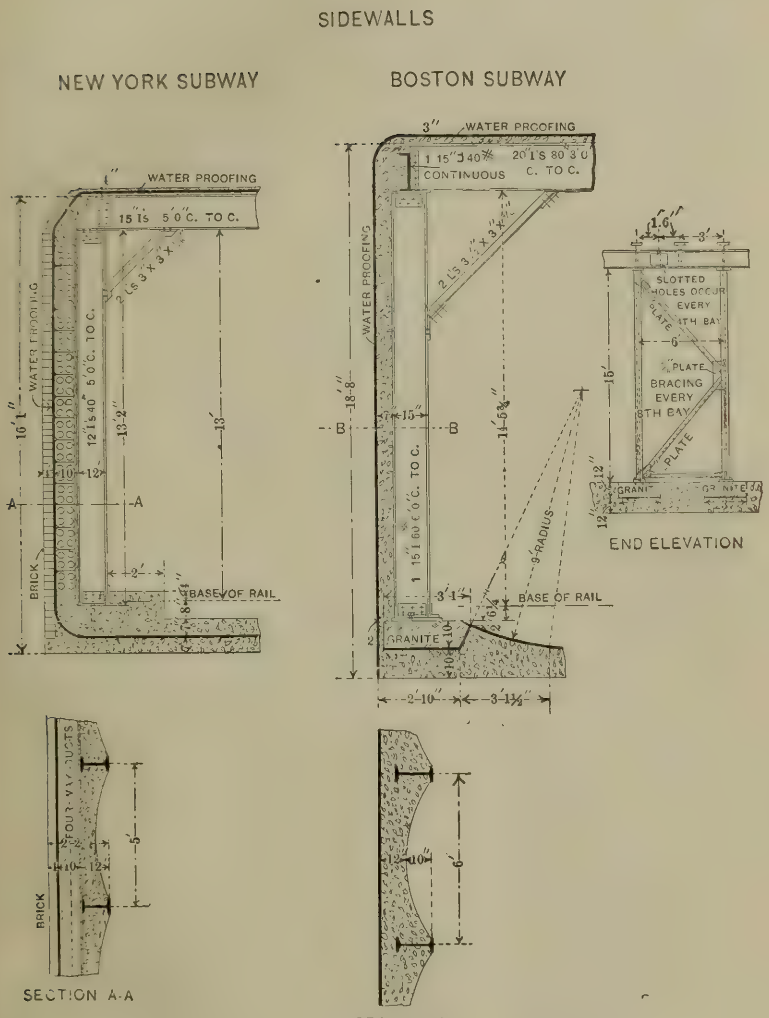
FIG. 2.—REINFORCED CONCRETE CONSTRUCTION, LENOX AVENUE, N. Y.

The only one of the foregoing structures which cannot be moved is the sub-conduit of the surface railway in New York. This conduit, which contains the conductor bar and provides a chamber in which can run the car plow with the contact shoe, has a depth of 20 in., and is carried, together with the track and slot rails, by iron yokes having a depth of 30 in. from the rail level. This last figure, therefore, fixes, in New York, the extreme possible approach of the top of the roof to the street surface. In many instances this minimum has been realized, although, as a rule, a small additional margin of a few inches has been allowed. Substantially the same minimum has been attained in Boston; but in Philadelphia the ordinances require that no part of the roof of the subway shall be within 4 ft. of the street surface. Such an approach necessarily involves an interference with and, at times, complete reconstruction or readjustment of the various sub-surface structures. Sewers are disposed of by building a separate line for each side of the street, delivering into transverse intercepting sewers, located as topography permits and passing beneath the subway. The various mains and electrical conduits are moved, the smaller ones remaining above the subway, the larger ones being moved to the sides. Transverse mains and conduits from cross-streets, if there be not room above the railway roof, can be passed beneath the longitudinal mains and through the roof of the railway, space being afforded by constructing a bay between the roof beams. The mains and conduits are thus arranged in two planes, the longitudinal lines occupying the upper plane, the transverse lines the lower. As these mains, exclusive of the sewers, in the ordinary unsystematic manner in which they have been laid, occupy a depth of as much as 6 ft., and can be compressed into a minimum depth of 2 ft. 6 in., the rail level can be brought 3 ft. 6 in. nearer the surface if the readjustment of the mains is undertaken. This raising of the railway decreases the amount of excavation, and diminishes, or at times obviates contact with ground-water and interference with the foundations of abutting buildings. From the point of view of operation, it brings the station platform in practise in New York to within 13.5 ft. of the sidewalk, in Boston to within about 15.5 ft. for elevated cars and 18 ft. for surface cars, and in Philadelphia, 21 ft.

The public inconvenience of readjusting the sub-surface structures during construction is great, the cost is considerable and difficult of accurate estimation, but the total cost of the work as compared with deep tunnel work is no greater, and, when the capitalized expense of running elevators is added, the actual cost is less, while the convenience to the public is incomparably enhanced.

2.—The Use of Steel Beams in Walls as Well as in Roofs.— As soon as the arched roof gives place to a flat roof, the latter, of necessity, consists of a system of beams. In Europe such beams rest on masonry walls. In American practise it is the custom to carry the roof beams on vertical beams at the sides, so that the walls are similar in construction to the roof. In Boston the wall beams form a subway 14.5 ft. high in the clear from the floor, or bottom of the rail, to the roof. They are from 12 to 15 in. deep, weigh from 35 to 60 lb. per ft., and are set at 6 ft. from center to center. In New York, for a subway 13 ft. in the clear, the beams are 12 in. deep, weigh 40 lb. per ft., and are set 5 ft. center to center. The feet of these columns are buried in the floor, which is always of concrete, and which acts as a strut from wall to wall. The columns, therefore, are held at top and bottom and can be treated as beams, resisting the pressure of the earth behind and whatever surcharge there may be from surface loads or the weight of adjacent buildings. When these weights are centralized, or more than usually heavy, the columns are increased accordingly. Between the columns there is a comparatively thin masonry wall to withhold the earth and to distribute its pressure to the columns themselves.

The advantages of using steel columns instead of an all-masonry wall are: Economy in first cost; rapidity in erection; economy in space occupied; lessened quantity of materials of excavation and construction handled, and uniformity in thickness of wall. While the economy in first cost, due to the fact that the beams with a thin wall and consequent small excavation cost less than a heavy masonry wall with greater excavation, is desirable, the other advantages are more important. In carrying out such a work as the building of an underground railway along a busy street in a great city, it is exceedingly desirable that the minimum of material be handled, that the minimum of space be occupied, that the walls



SIDEWALLS

NEW YORK SUBWAY

BOSTON SUBWAY

END ELEVATION

SECTION A-A

SECTION B-B

FIG. 12.

be, as far as possible, of uniform thickness, so that the sheet-piling or other bracing of the trench be in a continuous plane, and that sewers, water mains and other similar sub-surface structures can be laid alongside of the walls in straight lines without being affected by frequently occurring enlargements of the wall section; if increased extraneous loads have to be resisted solely by increasing the wall section. Finally, in many cases where the street is narrow or the available space much occupied by other structures, it is only by the use of the thin wall that the construction can be accomplished successfully.

In computing the necessary section of the wall columns, as well as the section of the roof beams, it was the custom, when designing the subway in New York, to take the actual dead load, *i. e.*, the weight of the superincumbent earth for the roof beams, and for the walls the weight of the earth pressures at the sides with its actual or assumed surcharge according to the ordinarily established rules, adding to these any specially concentrated or local loading, such as elevated railway columns and foundations, heavy adjacent buildings on shallow foundations, and then, in addition, assuming as a live load per square foot of street surface a weight varying from 200 lb. to a maximum of 1 135 lb., depending first on the width of the street, the railway streets being estimated on a heavier basis, as in that case the subway being nearer to the house, building material would therefore be more apt to be buried over the subway, or the subway might be subjected to the strain of a falling wall; second, dependent upon the amount of existing dead load. The greater the dead load the greater the amount of cover, and therefore the live load would be distributed over the greater area of earth. The diagram, Fig. 13, shows the live-load assumption.

Since the columns and beams are held throughout their whole length by the jack-arches, no allowance need be made for flexure, and, as the so-called live loads, if present in any such amount as assumed, will arise only from piles of building material and are therefore quiescent, it becomes permissible to assume a high unit stress for proportioning, which in New York was placed at 20 000 lb. per sq. in., for steel having an ultimate average of 64 000 lb., and an average elastic limit of 35 000 lb.

NEW YORK SUBWAY

DIAGRAM SHOWING PROPORTION OF LIVE LOAD ASSUMED FOR VARIOUS DEPTHS OF COVER

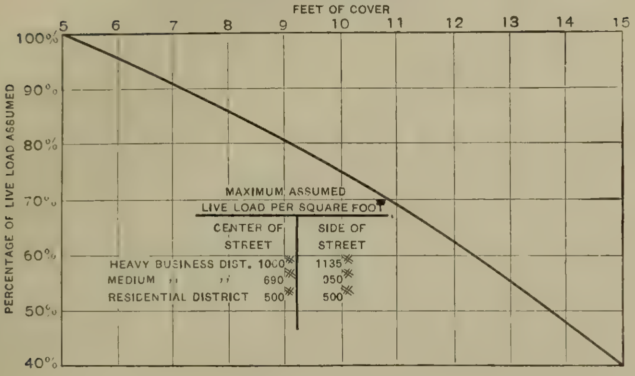


DIAGRAM OF LOADS (DEAD + LIVE) PER SQUARE FOOT VARIOUS DEPTHS OF COVER. VARIOUS LOCATIONS

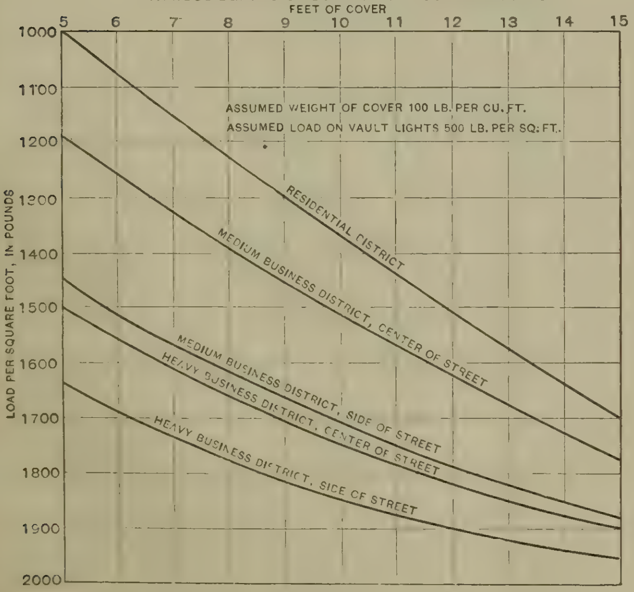


FIG. 13.

The same principle, of using a steel framework to withstand extraneous pressures, instead of balancing them by weight of masonry, has been applied to floor construction to resist upward hydrostatic pressure. In this case beams are laid in the floor, as well as in the roof and walls, and their section computed accordingly. When this is done the structure becomes a complete steel cage.

3.—Simplicity of Design in Steel Structure.—With so great an amount of steel used, being about 4 000 tons per mile of four-track structure, exclusive of the additional steel required for stations, it is obvious that the design must be simplified to the extreme, as by such simplicity the cost will be affected. It is the practise to use, as far as possible, rolled sections, and avoid plate, or built-up, members. To this end, the roof beams run transversely to the axis of the structure, and the use of main cross-girders, with smaller longitudinal girders framed in, is carefully avoided. In the first work in Boston longitudinal girders were placed between the tracks supported by columns at intervals of about 6 ft., the cross-beams of the roof resting on these longitudinal girders. It was found that an economy in steel resulted in omitting the longitudinal member and placing a column beneath each cross-beam, so that the beam interval fixes the column interval. In practise, two great advantages follow from this arrangement; one is that the omission of any longitudinal member obviates all special members and the necessity for careful adjustment in construction and inconvenient temperature variations during erection. Any slight variation in bent spacing is taken up without trouble in the jack-arches connecting them. The other advantage is that the closeness of the columns to each other diminishes the chance of structural damage resulting from a train derailment. The steel structure, therefore, is nominally reduced to rolled beams for the roof and walls, and to intermediate columns supporting the former. Except in extraordinary cases, one weight or section of wall column is generally applicable. The roof beams vary in section with the superincumbent load or assumed live load. In practise, it is found that a few changes in sections suffice for the greater portion of the work. For these variations in sections no change need be made in connections to wall or center columns, so that, with care in de-

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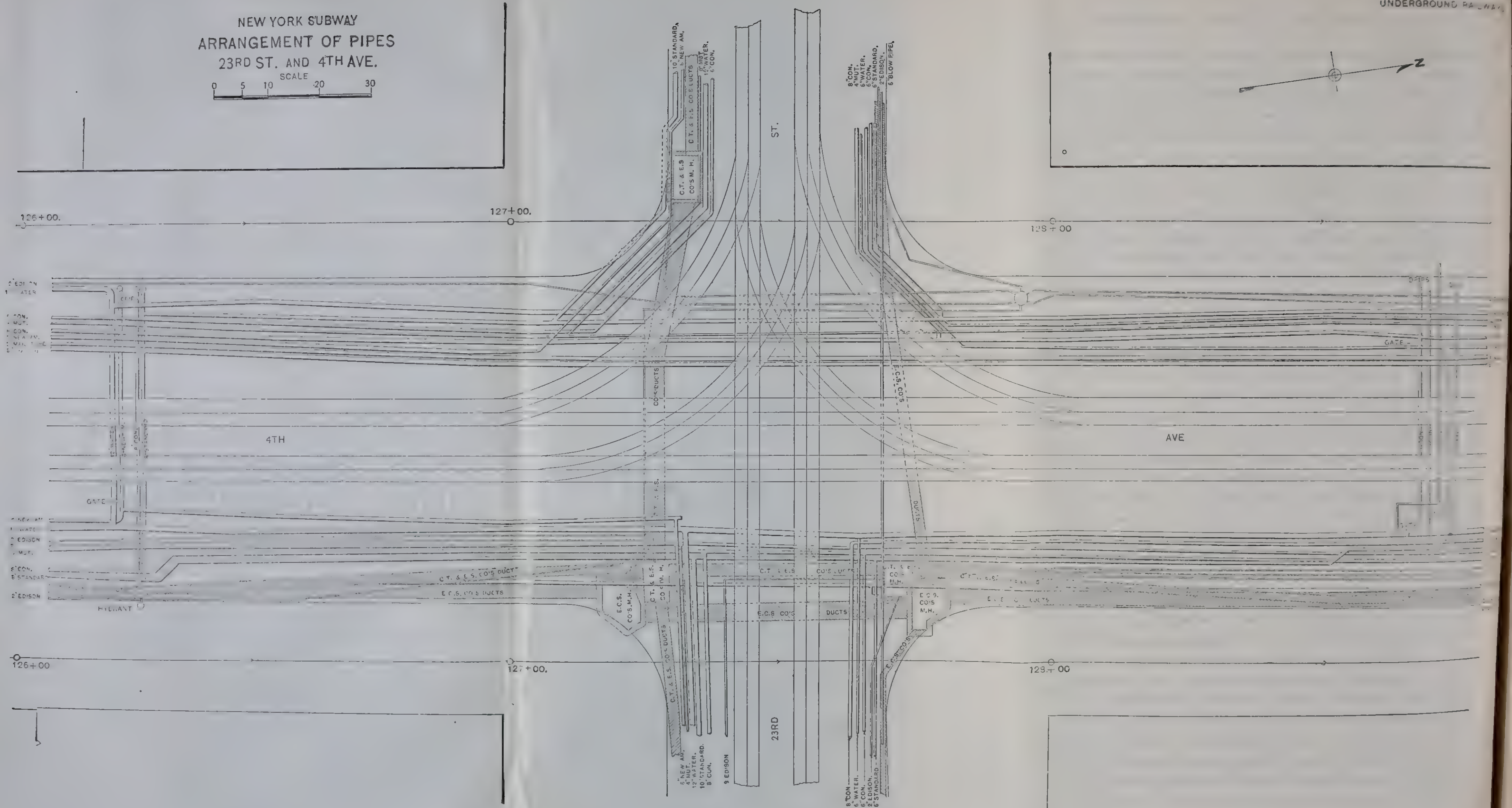
INTER. ENG. CONG., 19
PARSONS ON
UNDERGROUND RAILWA

NEW YORK SUBWAY
ARRANGEMENT OF PIPES
23RD ST. AND 4TH AVE.

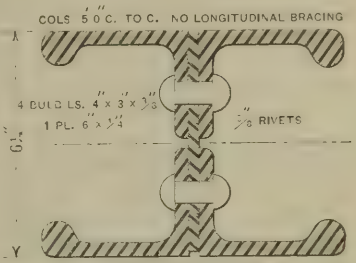


signing, the steel structure can be reduced to interchangeability of parts. A small sacrifice in the amount of steel used is economical to produce this result.

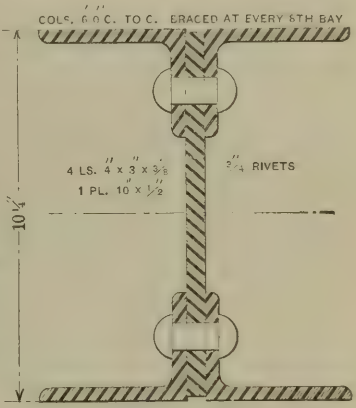
When, for special reasons, it is desirable to use longitudinal girders beneath the cross-beams, such girders are not made continuous, but rest on two columns with the ends cantilevered, so as to avoid special members, or special connections between contiguous longitudinal girders, with all the inconvenience above quoted of continuous longitudinal members.

As for intermediate columns, the most economical column is the one used in New York and partly followed in Philadelphia. This column consists of four bulb-angles connected by a web, the latter running transversely to the axis of the railway. The component parts of this column are easy to roll, and require but two rows of rivets to fasten them together. It is compact in section, while the bulbs at the angle extremities not only reinforce the angles against crippling from an accidental blow, but increase the radius of gyration of the section. Connections with these columns can be easily made in either direction. Finally, all parts are accessible for painting. The column, as illustrated in Fig. 14, is

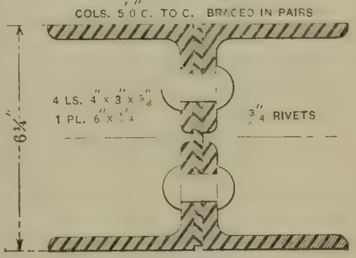
CENTER COLUMNS


COLS 5' 0" C. TO C. NO LONGITUDINAL BRACING
4 BULB LS. 4" x 3" x 3/8"
1 PL. 6" x 1/4"
7/8" RIVETS
6¼"

NEW YORK SUBWAY



BOSTON SUBWAY



PHILADELPHIA SUBWAY

FIG. 14.

composed of parts as small as are desirable to roll, and is somewhat in excess of section for ordinary conditions of loading. It therefore serves for all cases up to a dead load of about 10 ft. of superincumbent earth and assumed live load.

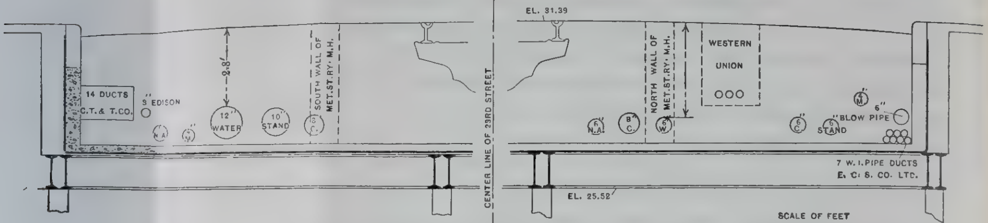
4.—The Use of Concrete Instead of Brick or Stone Masonry.—It is the established practise of the three works under consideration to use concrete wherever possible, instead of either brick or stone masonry. Concrete appears to possess advantages at every point. In the first place, it is more economical. In Boston the average contract price for brickwork was $14.60 per cu. yd. as against $8.80 for concrete. In New York, where good brick can be bought for from $6 to $8 per thousand, the sub-contractors bid on the average $15 per cu. yd. for brickwork and $8 per cu. yd. for concrete. Apart from this, the benefits in the work itself are equally strong. Concrete can be mixed by machinery and put in place by so-called unskilled labor. It is plastic, and flows around the beams of the roof and wall, and therefore comes in much better and more immediate contact than would the mortar of stone or brickwork. It also builds up faster than ordinary masonry. Where concrete is used in large masses it is permitted to embed pieces of rock to facilitate the work and diminish the cost, the New York Specifications on this point reading as follows:

> "*Size of stone.*—For all concrete the maximum diameter for broken stone or gravel unless specifically permitted by the Engineer must not exceed in any direction 1 in.
>
> "*Rubble concrete.*—In all concrete where the thickness is 30 in. or more, the Contractor may imbed in the same broken pieces of sound stone whose greatest diameter does not exceed 12 in. and whose least diameter or thickness is not less than three-quarters of the greatest diameter. These stones shall be set by hand in the concrete as the layers are being rammed, and so placed that each stone is completely and perfectly imbedded. No two stones are to be within 6 in. of each other, and no stones within 4 in. of an exposed face."

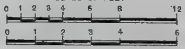
A similar practise obtains in Boston and Philadelphia. As illustrating the amount of concrete used, the Boston Subway has required 194 000 cu. yd.; New York, 550 000 cu. yd.; and Philadelphia, 45 000 cu. yd., assuming work under construction as completed. On the other hand, of brickwork of all kinds, Boston used 12 000 cu. yd. and New York 28 000 cu. yd.

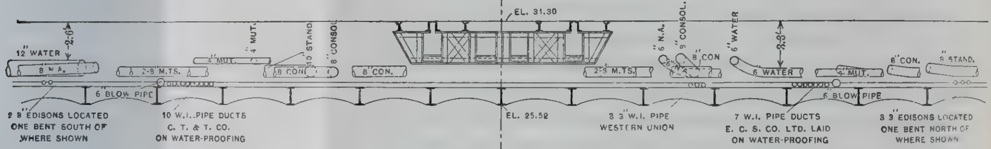
NEW YORK SUBWAY

SECTIONS OF PIPES, 23RD ST. AND 4TH AVE.

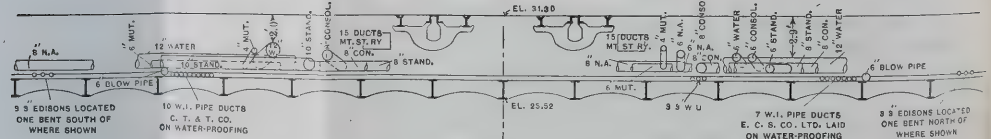


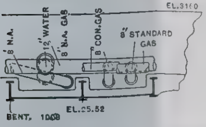
SECTION THROUGH WEST WING OF STATION LOOKING WEST



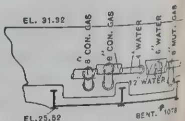

EL. 31.30
2.6'
12" WATER
8" N.A.
2-8" M.T.S.
4" MUT.
4" MUT.
10" STAND
8" CONSOL
8" CON
8" CON.
6" BLOW PIPE
2 3" EDISONS LOCATED ONE BENT SOUTH OF WHERE SHOWN
10 W.I. PIPE DUCTS C. T. & T. CO. ON WATER-PROOFING
EL. 25.52
2-3" M.T.S.
6" N.A.
8" CONSOL.
8" CON
6" WATER
6" WATER
3.8'
4" MUT.
6" CON.
8" STAND.
6" BLOW PIPE
3 3" W.I. PIPE WESTERN UNION
7 W.I. PIPE DUCTS E. C. S. CO. LTD. LAID ON WATER-PROOFING
3 3" EDISONS LOCATED ONE BENT NORTH OF WHERE SHOWN

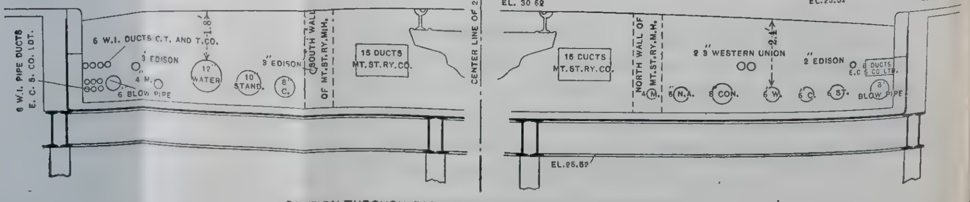
LONGITUDINAL SECTION OF 4TH AVE. WEST SIDE





LONGITUDINAL SECTION OF 4TH AVE. EAST SIDE





SECTION THROUGH EAST WING OF STATION LOOKING WEST

5.—*The Use of Reinforced Concrete.*—It is somewhat singular that the use of steel and concrete in combination should have been applied in America to underground railway construction, rather than in Europe where the general use of this excellent material is so much more extensive. Reinforcement of concrete by small rods wholly embedded was used on the Boston Subway to some extent in 1896 and thereafter. In 1900 it began to be used for the reinforcement of arches at the crown and other points where slight deformation had been observed or was apprehended, and, in the same year, for the reinforcement of flat roofs; but it was not until May, 1902, that it was regularly used on the Boston Subway for the reinforcement of flat roofs and side walls accompanying them.

In the New York Subway the above practise was followed, and a design was developed to eliminate beams from both the walls and roofs in standard construction, and a test section about one-third of a mile long was constructed. The result was so satisfactory that two stations 350 ft. long and 80 ft. wide were afterward built, and designs were prepared for a large part of Contract No. 2, being the Brooklyn extension now under construction. The floor of the subway is constructed in the ordinary manner in concrete, unless an upper hydrostatic pressure is expected when the concrete is reinforced with rods at points where tension is to be expected.

The walls have a thickness of from 14 to 16 in., depending on the side thrust. This thickness, however, is exclusive of the protective wall outside of the water-proofing and also of the space occupied by ducts. The walls in themselves are reinforced on the inside by 1¼-in. square rods, the number of rods varying from four to five per 5-ft. panel, according to the amount of side thrust. Opposite each column there is a special vertical member consisting of two 3 by 3 by ⅜-in. angles. The rods are set 2 in. back from the interior face.

The roof has a thickness varying from 18½ to 21½ in., depending upon the superincumbent dead or live load, and is reinforced on the bottom by 1¼-in. square rods, there being six or seven per 5-ft. panel according to the superincumbent pressure.

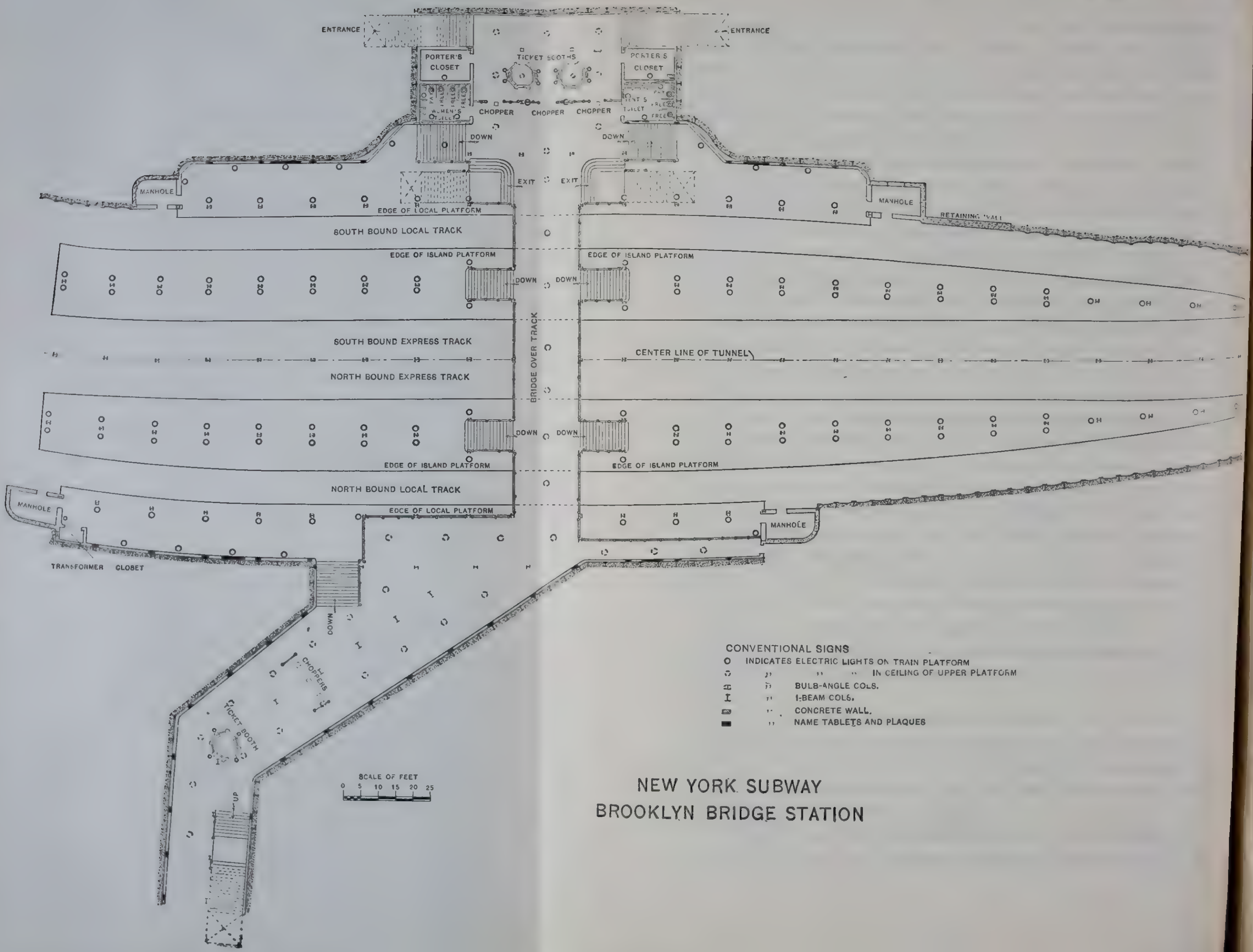
In order to distribute the thrust of the columns or take care of the possible tension on the upper face, rods, 6 ft. long, and 1¼ in.

square, are placed along the central part of the roof above the rows of columns. The roof rods are set 2½ in. back from the under face. Between the columns, and in order to form a longitudinal girder, the columns themselves are connected by three ⅝-in. round rods, the lowest rod being set about 22 in. below the line of the under face of the roof. The roof concrete is then brought down in curved form so as to enclose these rods.

As a result of experiments to determine the relative adhesion between concrete and rods painted, oiled and not treated (demonstrating that adhesion in the case of the first two should be only about 10% of the last), it was decided to leave unpainted and even unoiled the portions of the columns embedded in concrete and all the rods, relying entirely on the concrete to preserve the metal from corrosion. The concrete used is mixed in the proportions of 1 part cement, 2 parts sand and 4 parts broken stone, the latter not exceeding 1 in. in size. The concrete is mixed quite wet so as to insure its flowing around all the rods. The rods are held in position by tight wooden frames while the concrete is poured in the moulds. The advantages obtained are a less quantity of steel used, in about the ratio of 5 to 6, as compared with steel beams in walls and roof; the use of steel in a cheaper form; greater rapidity of construction, as all riveting and careful adjusting of steel framework is avoided; and the complete embedding of all steel except the intertrack columns, so that but little painting is required subsequently. Its disadvantage is its lack of early strength, in case it is desired to subject the structure to loading immediately after erection, which can be done with a steel-beam frame. Heavy concentrated loads such as superincumbent elevated railway foundations can be readily taken care of by supplementing the rod construction with beams, the latter to support the elevated railway foundation.

In the New York Subway, reinforced concrete is also used in arches, notably the Mott Avenue Station arch, with a clear span of 50 ft.; in reinforcing side walls; in specific foundations; in overhang of station platforms, and, in fact, at all points where concrete may be subjected to tension.

In the design of the underground railway in Philadelphia, the example and experience of Boston and New York were availed of



NEW YORK SUBWAY
BROOKLYN BRIDGE STATION

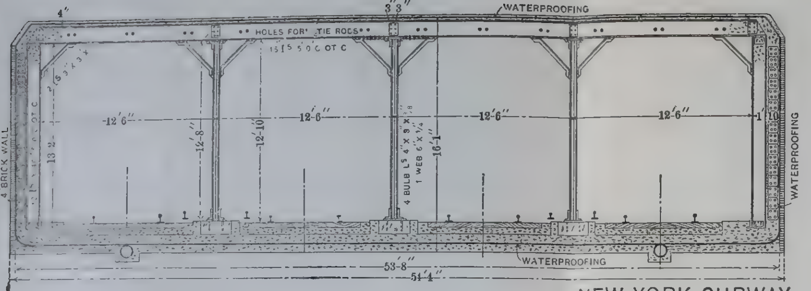
and reinforced concrete largely used. A portion of this road under construction has four tracks, and, as at first designed, was a complete example of reinforced concrete construction. As in New York, there is a row of columns, 5 ft. center to center, between each two tracks, these columns being set 12 ft. center to center laterally. The columns, composed of four 5 by 3 by $\frac{5}{16}$-in. angles, with a single connecting web, rest on the concrete floor, and were designed to have their tops project into the roof concrete. Near the top, two 12-in. channels were to be field-riveted to brackets on the column. These channels, surrounded with concrete reinforced with longitudinal ½-in. rods and lateral 3-in. rods, formed girders to support the roof between the columns. The roof concrete had a thickness of about 2 ft. reinforced with longitudinal rods ⅝ in. in diameter, spaced 18 in. apart and set about 6 in. upward from the lower face, and reinforced with transverse rods 1⅛ in. in diameter, spaced 6 in. apart and set between the lower face of the roof and the above-mentioned longitudinal rods. Further, in order to distribute the column reactions and provide against any tensile strain in the upper layer of concrete over the column tops, ½-in. transverse rods, 6 ft. long, were spaced 4 in. apart. The wall including the protective concrete outside of the water-proofing layer, and also including the terra cotta ducts for carrying the electric cables, with a width of about 10 in., has a thickness of about 3 ft. The chief resisting portion, however, is the thickness of about 16 in. next to the inside face. This is composed of concrete mixed in the proportion of 1 to 2½ to 5, the stone being broken to a 1-in. ring size and reinforced with vertical rods, 1⅛ in. in diameter, spaced 8 in. apart, and horizontal rods, ⅝ in. in diameter, and 24 in. apart. The vertical rods are set close to the inner face, and the horizontal rods immediately behind them. The columns are further stiffened by concrete bulkheads 6 ft. 6 in. long and about 6 ft. high above the floor, but alternating with openings 2 ft. 6 in. long. These bulkheads are reinforced with longitudinal rods ¼ in. in diameter, spaced 12 in. apart, and a few short transverse rods.

Before commencing construction the plans were changed so as to substitute a beam roof.

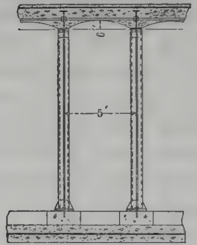
6.—The Addition of Extra Tracks for Express or Special Service.—The three lines under consideration have each, for a portion of the route, more than two tracks. In Boston the additional tracks made a four-track line, all four tracks being intended for (and were for several years used for) trolley cars which became surface cars after passing the limits of the subway. At present, two of the four tracks are used temporarily by trains running over elevated structures in the outlying districts, but, as soon as a new neighboring parallel subway can be built, the "elevated" trains will be placed in it and all the tracks of the old subway will be restored to their original use. The arrangement in Philadelphia is similar to the present arrangement in Boston. In New York the additional tracks are provided to furnish express facilities, so that in the same railway two kinds of service are provided, one for local needs, that is trains stopping at intervals of about ¼ mile, and the other for a longer distance travel with stops averaging 1½ miles. The local trains make an average speed of about 15 miles per hr., the express trains, owing to the fewer stations, a speed of about 30 miles per hr., time lost in stops included in both cases. For the 7 miles traversing the portion of the city where there is the densest traffic, this four-track arrangement permits the running of express trains in both directions. Beyond this section three tracks on two diverging lines are provided, enabling an express service to be furnished in the direction of major traffic, that is, southward to the commercial district in the morning, northward to the suburban residential district in the evening. In order that full advantage may be taken of this opportunity for fast service, the trains in New York are equipped with a greater amount of power than has hitherto been realized in actual practise. The trains are to be self-contained as to power, that is, propelled by motor cars and not by locomotives. The motor cars have each two 200-h. p. motors, and the train make-up is so adapted that an express train will consist of five motor cars and three trailers. Each motor car weighs when loaded with passengers 43½ tons, and the trailers 33 tons, or say, 316½ tons for the train complete. The nominal horse power per ton of trains is therefore 6.32. This power, however, can be increased greatly during the period of acceleration, when there will be available about 10 h. p. per ton of train.

7.—A Freedom in Design, Whereby the General Type of Structure is Changed to meet Local Requirements.—From what has pre-

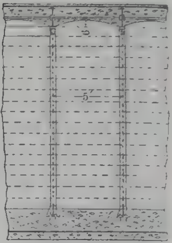
PLATE XXXIX. VOL. LIV. PART
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
PARSONS ON
UNDERGROUND RAILWAYS.



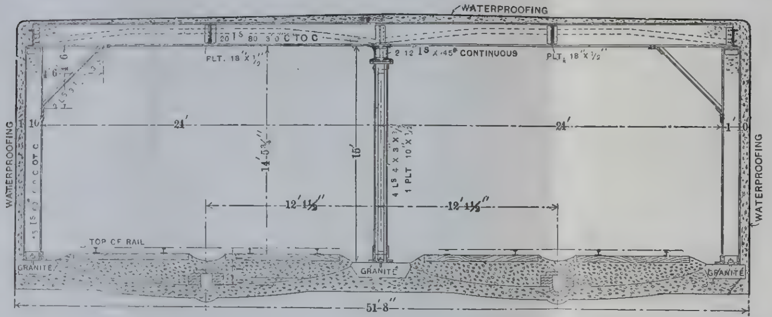
NEW YORK SUBWAY



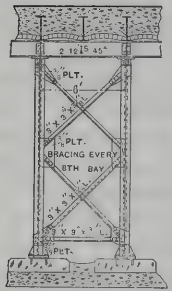
CENTER COLUMNS



SIDE WALLS



BOSTON SUBWAY



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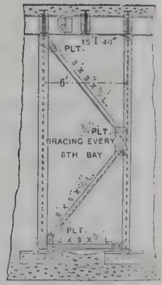
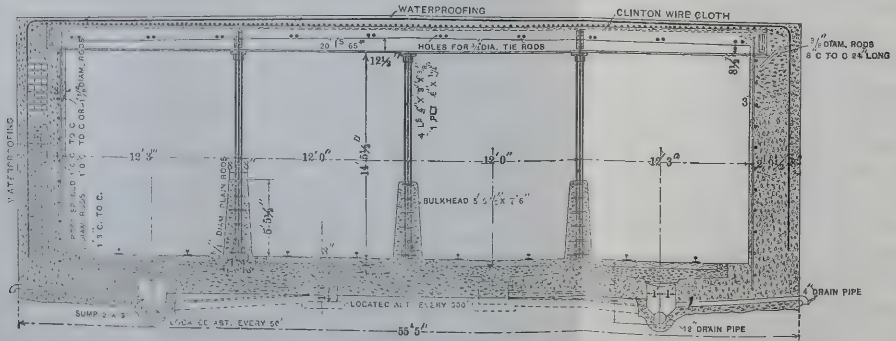
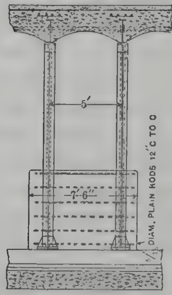


SIDE WALLS



PHILADELPHIA SUBWAY



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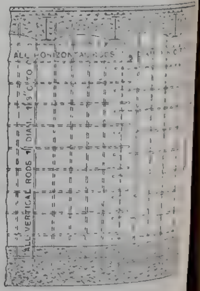
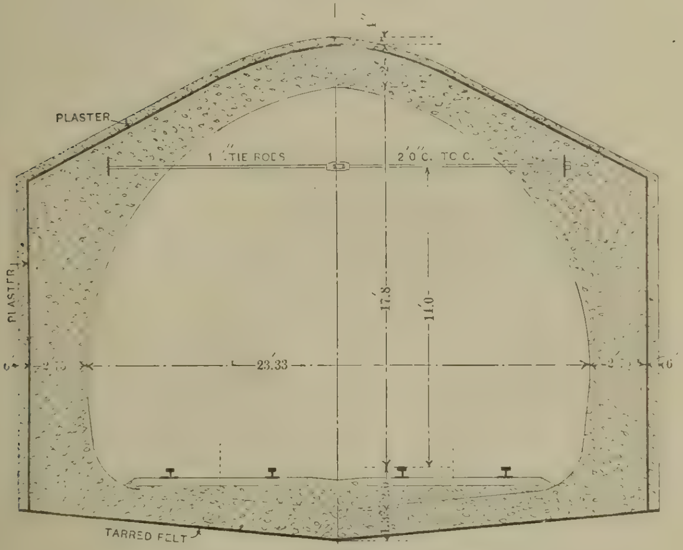


SIDE WALLS

ceded it is seen that the American underground railways have been designed to accommodate two kinds of traffic, either train and individual surface cars, or express and local trains, and therein they present distinctly different characteristics from underground railways of other countries. This basal feature in design inevitably involves varying designs in structure in order that the two services may be accommodated satisfactorily and mutually. Stations of different types are at once involved, depressed tracks to make junctions with the central tracks and avoid rail crossings of the upper ones are necessitated. When once the uniformity of design has been broken, other variations will always follow. Therefore, although the general type of American underground railway can be said to be a structure with a flat roof supported by rows of columns between the tracks, the designers of the subway have not hesitated to depart from this standard whenever local conditions gave proper warrant for so doing, and in considering American

BOSTON SUBWAY



APPROACH OF EAST BOSTON TUNNEL

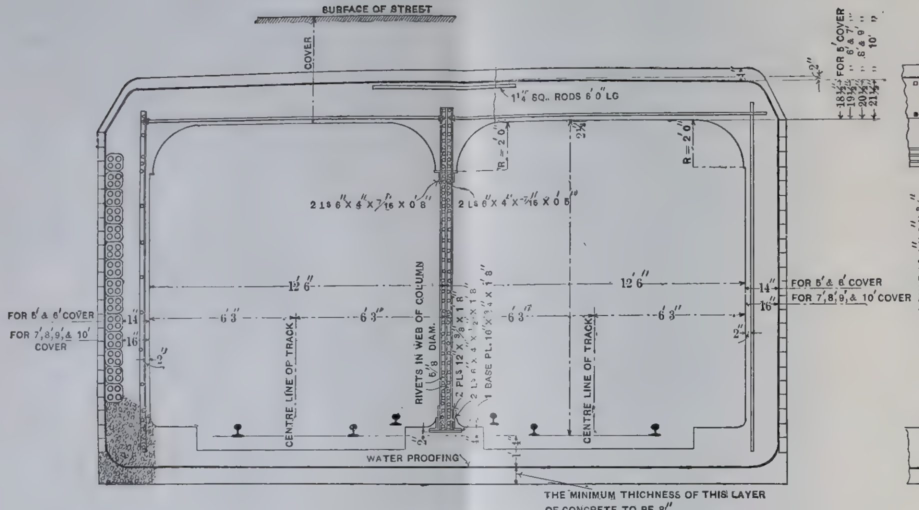
Fig. 15.

practise this freedom of variation or departure is a characteristic to be borne in mind. Thus, in Boston, of a total mileage of 4.3 miles, 45% is in two-track standard or reinforced concrete, flat-top section, 15% is in four-track standard section, 18% is in two-track arch section, some built in cut and cover and some by a half-shield, and 22% is in sub-aqueous arched work under compressed air. Similarly, in New York, the total length of subway constructed or under construction is divided among the following types:

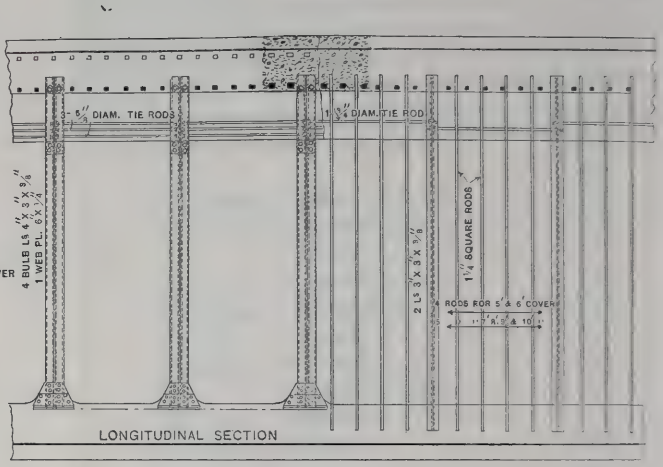
		Miles.
Single-track.	Arched	0.14
Double-track.	Standard	4.17
“ “	Arched	3.95
“ “	in single tubes	1.36
Three-track.	Standard	2.20
“ “	Arched	0.17
Four-track.	Standard	5.64
“ “	in two-track arches	0.38
Five-track.	Standard	0.74
Eight-track.	Standard	0.25
Total		19.00

The last two types cover yards and sidings. Of all the above, 14.22 miles are in cut and cover, 3.42 miles in ordinary tunnel, counting the four-track work in double tunnels as the equivalent length of actual tunnel, and 1.36 miles in tubular tunnel, for the most part under compressed air. In the case of both Boston and New York, in addition to the above variations in type of structure there are many minor variations, all requiring special treatment, such as cross-overs, tracks passing beneath other tracks, loops, etc.

Such are what may be termed the main characteristics that mark American design in underground railways. In other respects, the practise follows usual American standards. The permanent way consists of wooden ties, not preserved except as protected by tie-plates, laid in fine broken-stone ballast and carrying heavy rails, the heaviest section being used in New York, where the weight is 100 lb. per yd. In order to maintain a fast-running service at the minimum interval, automatic home and distance signals are

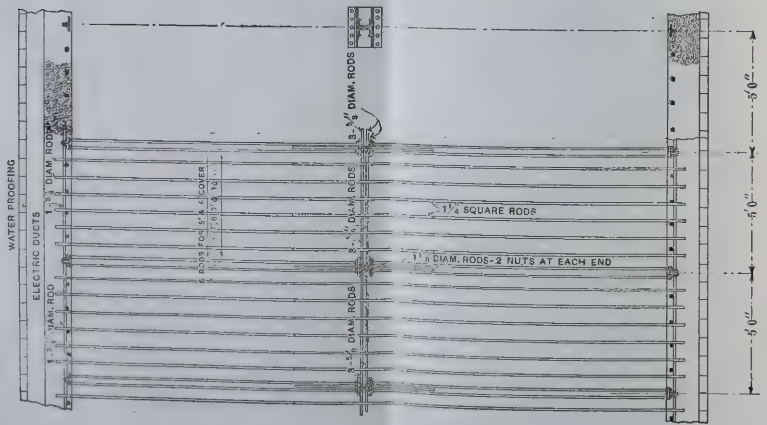


CROSS SECTION

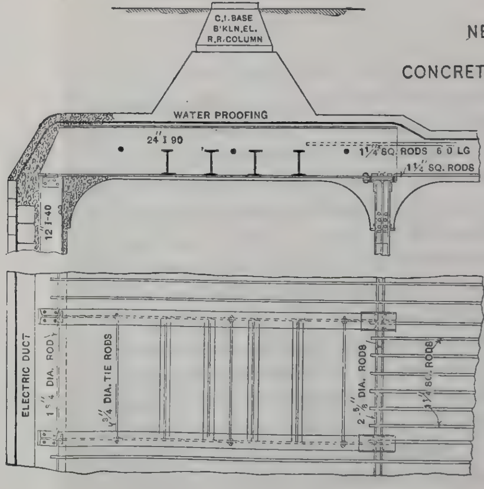


NEW YORK SUBWAY

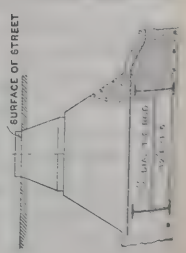
CONCRETE STEEL CONSTRUCTION



PLAN

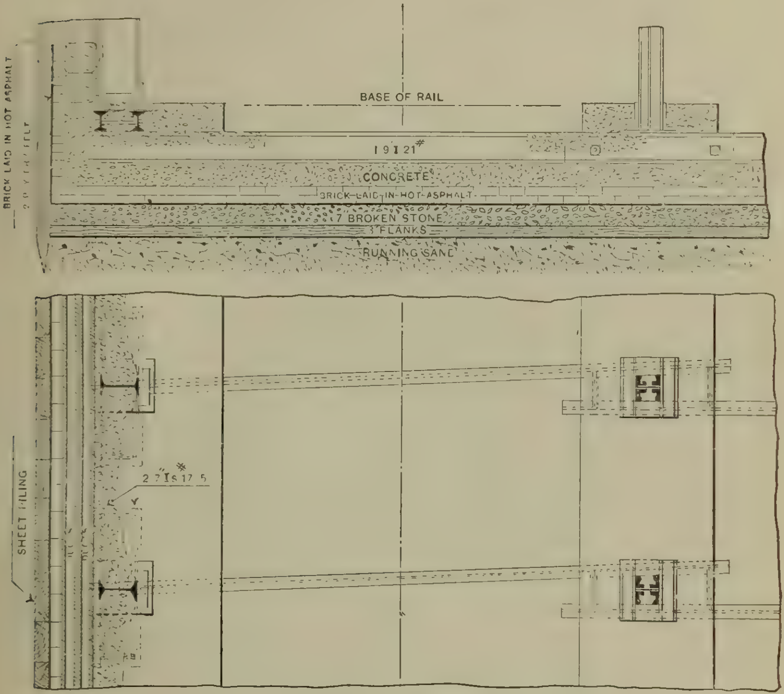


SUPPORT FOR ELEVATED R.R. COLUMNS
3-TRACK TUNNEL ON FLATBUSH AVENUE



adopted, and, in addition, an automatic device whereby if a motor man over-runs a signal, power is at once cut off the train and the brake is applied.

In operation usual American practise is followed. There are no classes, and a uniform fare of five cents, regardless of distance, is charged, while the cars are of the ordinary type with end doors.



NEW YORK SUBWAY
FLOOR CONSTRUCTION IN SOFT MATERIAL
BELOW MEAN HIGH WATER
FIG. 16.

Both end and middle doors are used in Boston. In order to reduce to the minimum the chance of fire, the cars for the New York Subway were designed with a metal underframe, and the floor is covered on the underside with a special asbestos product; all wiring is carefully done, parts subject to short-circuit are separated and all points of electrical connections are isolated in asbestos fire-proof cases. Work, however, has been begun on an all-metal car of which there is every promise of ultimate success, and, at a cost and of a weight, no greater than a well-built composite car as described above.

Power is universally electric, and furnished to the trolley cars by the usual overhead wire and to the trains by a third rail. On the trains the power is utilized on motor cars, said motor cars being under a multiple-unit control. The power is carried through the subways, in the case of New York and Philadelphia, by cables drawn through terra cotta ducts built in the side walls and thus protected fully against damage by train derailment. The cables are led to the ducts through manholes directly from the street surface. The power itself is produced in large central stations by alternating-current dynamos of the ordinary type, sending out the current at high voltage (11 000 volts) transformed and reduced in sub-stations to direct current at 550 volts, at which pressure it is fed to the line. In size such central stations attain large proportions. In order to supply the necessary power for the rapid transit service in New York, on 68.6 miles of running track, partly underground and partly elevated, the main power-house is 693 ft. long and 210 ft. 8 in. wide, and 123 ft. high. It contains, as the basis of the main plant, eleven generating units rated nominally at 5 000 kw., and capable of delivering, at the time of maximum load, 7 500 kw. each. Each is operated by a separate engine with a capacity of from 7 500 to 11 000 h. p. These generators are of the three-phase, alternating-current type, 25 cycles per second, and operating at 11 000 volts. The total energy produced when the engines are worked to their full capacity, including the substitute engines, is 132 000 h. p. This represents the largest steam-driven power installation hitherto constructed, and, as such, is interesting.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS, 1904.

DISCUSSION ON UNDERGROUND RAILWAYS.

By Messrs. Robert Moore, Samuel B. Fisher, Moritz Wormser,
E. E. R. Tratman, W. M. Camp, George A. Kimball,
George W. Parsons, Wilkie Woodard
and Howard A. Carson.

Robert Moore, Past-President, Am. Soc. C. E., St. Louis, Mo.— Mr. Moore. In comparing the two systems described in the papers under discussion, namely, the deep tunnels of London, built and owned wholly by private capital and enterprise, and the shallow subways of Paris, New York and Boston, built, in large part, by the capital and credit of the city, there can be little doubt but that the latter system is much the better. This system has the great advantage of keeping the enterprise, in all its parts, under the control of the municipality, which can then provide for such lines and for such details of construction as will best serve the needs of the people. Where the whole enterprise is left in private hands, the convenience and lasting welfare of the public at large is apt to be sacrificed to consideration of immediate pecuniary profit.

The speaker, from a limited experience, can confirm the statements of Messrs. Mott and Hay as to the very unsatisfactory ventilation of the City and South London Tunnel as first built. Unless its condition in this respect has been radically changed, it certainly needs some artificial method of ventilation.

In the original construction of the shallow tunnel at the west end of the Eads Bridge in St. Louis, Mo., a number of openings were left in the roof as a means of ventilation. They have since

Mr. Moore. been closed, as they did not accomplish the purpose intended, but seemed to confuse the air currents rather than promote them, and an exhaust fan was installed near the center of the tunnel. The conditions in the tunnel would, no doubt, have been different, if it had been operated by electricity.

In regard to the matter of cost, the Paris subways are said to have cost 3 400 000 francs per km., or, say, $1 000 000 per mile, which is much more expensive than any elevated line that has been built.

The speaker is also of the impression that the elevators used in the London subways must, if there is a heavy traffic, be a source of considerable delay.

Mr. Fisher. SAMUEL B. FISHER, M. AM. SOC. C. E., St. Louis, Mo.—The most striking feature in the general plans for underground railways, as given by Messrs. Parsons and Biette, is the radical difference in the sections which have been adopted in New York and in Paris, but the one in Paris is constructed entirely of concrete with a thickness of about ½ m. It looks as if, under certain conditions, the construction adopted in Paris might be made at less cost than the one used in New York.

Another noticeable feature is that, with the exception of the provision made for wires in New York, no provision is made, in these sections, for taking care of underground pipes and wires. All the papers treat of the necessity and difficulty of taking care of the pipes, but there does not appear to have been any definite provision made for taking care of them in the subways.

Mr. Wormser. MORITZ WORMSER, ESQ., New York City.—The original plans of the New York Rapid Transit Commission provided for pipe galleries running alongside the subway, in which water, gas and sewer pipes, and electric ducts were to be carried. But there proved to be legal objections to such a scheme, threatening a long delay for the work, and to avoid this, the pipe galleries were definitely abandoned. For a part of the line, water as well as gas and sewer pipes run under station platforms, but, between stations, these pipes are laid outside the subway structure, for the reason that, at the stations, the structure occupies the whole width of the sub-surface, and there is not sufficient room between the roof of the subway and the surface to permit these pipes to be laid there.

The contract plans call for a ventilating shaft and fan to be located at the deep-tunnel section under Central Park, but the fan itself has not as yet been installed. In general, however, there have been no special ventilating appliances provided, the idea being that the trains would provide sufficient fresh air, coming from the station entrances and exits which are numerous (usually eight at each station) and wide (5 to 10 ft. in width, and 8 ft. in height), without artificial aids. A further reason, which, it was considered, would render ventilating appliances unnecessary, was that the subway structure is very wide (50 ft.), being of four-track section on the main line, and consequently airy and spacious in itself. Finally, as the ends of the line consist of several miles of viaduct structure, the cars would be thoroughly aired there. Mr. Wormser.

At some points, specific aids to ventilation are required to suit local conditions. Thus, at Fort George, in the upper part of New York, the line is a deep rock tunnel, about 110 ft. below the surface at the deepest point, and about 2 miles in length. On this stretch, two stations are provided with what may be considered air-shafts, in which, at the same time, the elevators for carrying passengers to and from the two stations will be located.

In connection with the question of the ventilation of the New York Subway, it is necessary to mention a series of air-shafts situated along a part of Broadway for a stretch of about 2½ miles. Altogether these are twenty-five in number, 7 by 15 ft. in area. Here the line is directly sub-surface, and the openings, located in the parkways in the center of the street, are fenced in by ornamental railings, and protected by wire screens against objects that might be thrown into the subway either out of malice or mischief. Their purpose, as stated, is to provide fresh air in addition to that supplied through the stations. Finally, there is provided a shaft, 8 ft. in diameter, to ventilate the twin tube under the Harlem River. This shaft is located at the two-track section, before the twin tubes are entered, and its ventilating effect is complemented by a station just beyond the other ends of the twin tubes. Thus, summing up the ventilating provisions of the subway, there are no general or artificial means for its ventilation, the structure, as a whole, being spacious and airy, and the electrical operation of the road reducing contamination, but special provisions have been made at those sections of the line where local conditions require them, or where it was especially convenient to establish them.

With regard to the question of lifts, there were only three stations on the present line of the New York Subway which had to be provided with them. These are situated in sections of the city which are not densely populated, and hence only two elevators are to be provided at each. The respective depths of the station platforms below the surface are 109, 97 and 52 ft. At all other stations of the subway, the difference between the platform and street level is not much more than 15 ft., and for such a short distance lifts would not be necessary. At the Manhattan Street arch, where for a short distance (about ½ mile) the subway goes over arch and viaduct structure, and where a station is located, there will be two escalators, one ascending and one descending. The original plans called for stairways, but the considerable height above street level, 54 ft., it was thought, would warrant the provision of the mechanical device.

Mr. Tratman. E. E. R. TRATMAN, ASSOC. M. AM. SOC. C. E., Chicago, Ill.—It is specially interesting to note the active participation of the Municipality of Paris in the planning and the construction of the underground railway system of that city, as described in M. Biette's paper. In New York and Boston there has been similar participation, through the agency of special commissions appointed for the purpose. In London, however, the various lines have been built by different private companies to serve certain routes or districts, and each project has been opposed by rival projects, and by existing lines which anticipated an invasion of what they considered their own territory. Usually they also have to meet more or less opposition on the part of the municipal authorities. There has been no attempt at a complete system of local transportation to serve the city as a whole, and the result of this lack of system has been so chaotic that, about two years ago, a special commission was appointed to investigate the entire problem of city transportation for London, and, meanwhile, new projects have been held in abeyance. In connection with projects for new streets through certain sections of the city, it has been proposed to build a shallow subway system to take the electric street cars, bringing them into the congested districts (where they are not now admitted) without interfering with street traffic.

In regard to the vibration caused by electric underground railways, no trouble was experienced with the earlier deep-level lines in London, but, after the opening of the Central London Railway, there was such general complaint along the route of this line that the Board of Trade appointed a special commission to investigate the matter. The commission's report was made in 1902. The main cause was found to be the use of electric locomotives in which an excessively large load (32 out of 44 tons, or 8 tons per axle) was not carried by springs, the object being to avoid gearing in the locomotive. The effect of this was aggravated by the use of a track construction of insufficient rigidity and having rails with a wavy surface. The rails are of bridge section, but no room could be made for replacing them with deeper and stiffer rails without reducing the narrow clearance between the cars and the roof of the tunnel. On this point, the commission reported that it was unfortunate that such a small clearance had been adopted. The company then tried some geared locomotives of 33 tons, with only 2½ tons per axle not carried by springs. With these, the vibrations were less than one-third as many as those caused by the original locomotives. Experiments were also made with trains having motor cars and operated on the multiple-unit system; the motor cars weighed 20 tons, with only 5¾ tons not borne by springs. With these, the vibrations practically ceased, and this system was, therefore, adopted. The commission, however, recommended that, in new lines of this kind, a deeper rail should be used. Mr. Tratman.

Mr. Camp. W. M. Camp, M. Am. Soc. C. E., Chicago, Ill.—In summing up the American situation, Mr. Parsons omits mention of underground railways for freight transportation. The cities in the East have been constructing underground railways for the transportation of passengers, while, in Chicago, much preparation has been made for hauling freight on such routes. In the business center of Chicago, a great deal of heavy freight is hauled over the surface by teams. Coal and wholesale merchandise are two large items of such traffic, and the streets are crowded.

For some years these underground freight tunnels have been under construction by a private corporation, and something more than twenty miles of underground railway will soon be put in operation. The subways are single-track structures, 6 ft. wide and 7½ft. high, in the clear, and their depth under the streets is such that, should the city at any time undertake to build passenger subways, there will be room to put them in above the freight tunnels. The tunnel lining is concrete.

These tunnels run out several miles toward the suburbs and connect with the principal freight stations. The intention is to deliver coal to the office buildings and to take away ashes; then to connect with the wholesale establishments and handle the large tonnage of bulky freight. Later, if the scheme works to the satisfaction of the promoters, the subways may be extended far into the north, west and south sides of the city, for heavy freight and package delivery. It is thought that as much as 90 miles of subway might be operated on a paying basis.

The trains will consist of electric locomotives hauling specially designed trailer cars. The latter are of the combination flat and gondola pattern, constructed entirely of steel or iron. They are 12 ft. long, carried on two 4-wheel trucks, with a capacity of 30 000 lb. The cars and space available in the subways will permit the carriage of anything that can be taken through the door of a standard box car of steam railroads. The gondola car, for hauling coal or ashes, is 4 ft. wide, stands 5 ft. 3 in. high above top of rail, and has a box, 10½ ft. long. Coal or other loose material may be side-dumped by tilting the cars. The pressed steel sides may be removed, and the car changed to a flat car, on which large packages, barrels, etc., may be loaded and held in place by T-iron stakes inserted in pockets on the side sills. For carrying mail and other packages, a hood is placed upon the gondola car and hinged at the sides. The cars have 14-in. wheels and will pass around curves of 15 ft. radius. One of these cars was exhibited at the Louisiana Purchase Exposition.

The track is narrow gauge, and transmission is by means of a

Mr. Camp. bar of steel, or so-called "third rail," in the middle of the track, on wooden supports. This is also a rack-bar, and rack and pinion will be used to assist locomotive traction.

An interesting feature of the work of constructing these subways is that the excavation has been entirely by tunneling. There has been no cut-and-cover construction at all. Work has been carried on without any interference with street traffic. At points near the Chicago River and near the Lake Front, the material has been hauled out in tram-cars and dumped either into scows and pulled out into the lake, or hauled directly to the Lake Front. At points distant from the lake or river, the excavated material has been taken up in elevators to the street level and hauled away by teams at night, when the streets were not crowded with vehicles.

It would seem that the idea of hauling freight in the largest cities by underground routes should receive careful study, for it must be considered that the overcrowding of the streets by heavy teaming is one of the conditions operating to drive street cars off the surface and make the progress of pedestrians tedious. Conveyance of a large tonnage of freight any considerable distance by teams is also costly, and the presence of so much animal life renders the streets dirty and unhealthful. For example, it has been estimated that in the business section of Chicago, limited to an area of 2 miles square, an average of over 110 000 tons of freight is hauled through the streets every week-day. Over 70 000 trucks are regularly employed in making the delivery of this enormous quantity of freight, at an expense exceeding $50 000 000 per year. It is calculated that the subways can take care of half of this large freight movement, and if this comes to pass the relief so brought about will be of untold economic value.

As yet the practical operation has not started. So far as the experiments have been carried on no trouble from vibration seems to have developed. The speed has not as yet been officially stated, but the speaker has seen unofficial statements to the effect that speeds of 15 to 20 miles per hour were being made in the experimental runs.

The company which carried out the construction up to 1904 was the Illinois Telephone and Telegraph Company. That was reorganized into the Illinois Tunnel Company. During November, 1904, the company was again reorganized under an incorporation known as the Chicago Subway Company, the control of which is now in the hands of the financial heads of the great steam railroad lines entering Chicago. The franchise permits the use of the subways for telephone and electric power circuits, as well as for tracks for freight haulage, and the circuits of an automatic telephone system have already been strung. These are placed in hangers along the intrados of the tunnel arch.

Mr. Kimball. GEORGE A. KIMBALL, M. AM. SOC. C. E., Boston, Mass.—We are under great obligations to the authors of these three papers for the important information they have given, covering, as they do, the general subject.

All the papers describe structures which were built in congested cities, for the accommodation of local or municipal transportation, where it was necessary to provide an avenue of travel either above or below the busy streets. In congested cities, it is frequently an interesting and difficult problem for engineers to decide between the underground and the overhead structure. The underground is less attractive to passengers. The construction cost of a shallow underground structure is at least double that of an elevated structure, and passengers are subject to greater danger in case of accident which may be followed by fire or panic. On the other hand, the elevated structure is considered, in some places, as unsightly and an obstruction to light and air. In some American cities, the franchise for its construction is granted on condition that owners of property abutting on the streets through which it is constructed shall be compensated for all damage arising from its construction and maintenance. These damages, if any, added to the cost of construction, materially increase the cost of the elevated railroad.

In both underground and elevated railroads, it is important to the traveling public that the stations be near the surface, thereby avoiding the use of elevators, which cause delay and inconvenience to people taking trains, and are an added cause of congestion at stations where large crowds of people must be moved during the rush hours.

The operation of elevators is also a source of danger to passengers, causing accident, compensation for which is liable to add another item of considerable magnitude to the expense of transportation. The deep tunnels in London are subject to this inconvenience, and, in the speaker's opinion, it seriously affects their efficiency for relieving the street congestion.

Mr. Parsons. GEORGE W. PARSONS, ASSOC. AM. SOC. C. E., Steelton, Pa.—The speaker does not think that moving stairways would be suitable for deep subways. They work practically at an angle of 45°. That would be the greatest angle, and it would necessitate the use of much more land. In London during rush hours, he did not experience any delay at the "tuppenny" tube. There were five or six lifts, side by side, one of which was always ready; each lift carries probably seventy people. The greatest danger attending the use of those lifts during rush hours was due apparently to feeble persons stumbling or falling while entering. With entrances to lifts as wide as possible, with folding screen doors, and the floors level with the floors of the gangways, it is astonishing to see how quickly a great crowd can enter and leave one of those lifts. While the

Mr. Parsons. speaker does not know the exact rate, the lifts run at a very good speed. The question of providing for a crowd in a deep subway is a question of providing plenty of lifts. The engineer designing such a plant has to have large notions, because soon after the road goes into service, the number of people increases, and, in a year or two, may much exceed that estimated.

At Shepherds Bush Station, the crowd is not quite so great as on the New York and Boston subways during the rush hour, but the largest crowd is at the Bank Station. It is true, also, that a London crowd does not rush like a New York or Boston crowd. It moves with more deliberation.

The use of the escalator requires some education on the part of those who use it. There are many people who are likely to get in the way of others at one end of the trip.

Mr. Woodard. WILKIE WOODARD, ASSOC. M. AM. SOC. C. E., Cincinnati, Ohio.—This discussion is very interesting to the speaker, because, in Cincinnati, we are figuring on building a union passenger station and subway to be used by all the roads entering the city. The passenger station is to occupy one block (200 by 400 ft.), and the train-sheds are to extend a block, or 430 ft., farther on either end, which will give a train-shed, 1 260 ft. long, the passenger station being built over the train-shed. As this is the terminal point for the roads entering the city, the trains from the East will use the eastern end and those from the West, the western end of the train-shed. It will contain ten tracks, grouped in pairs for passenger service, and, as they will be used from both ends, will really give twenty tracks.

The subway connecting this station with the different railroads will be 100 ft. in width, which is wide enough to accommodate, in the clear, seven tracks: four as approach tracks for the station; two for the interchange of freight between the East and the West; and one as a bulk track; this bulk track being necessary to serve such concerns as may lease the right of way above the subway for manufacturing plants, commission houses, etc. We feel that four approach tracks to the station will be sufficient for fifty years to come.

The right of way will be through private property acquired by condemnation or perpetual leases, and, in that way, we can build our subway on our own property, asking the public for nothing but permission to go under the streets which we cross, guaranteeing that they will be replaced in fully as good condition as they were before we began.

The question of the ventilation of the subway has been given considerable study, for 8 000 of the 12 000 ft. of this line will be enclosed. It is not thought that it will give much trouble, for the clearances between trains and between trains and the roof of the subway will be large, the tracks being 13.75 ft., center to center, and the height of the subway being 18 ft. from top of rail to bottom face of roof. The motive power used will, undoubtedly, be electricity, so that there will be no smoke to contend with. Mr. Woodard.

In the train-shed, the clearance will be at least 25 ft., if we use the flat roof, as in the stations of the New York Subway, and if we use the dome construction, it will be 50 or 60 ft.

There are five different railroad passenger stations in Cincinnati, the shortest distance between any two being 3 000 ft., and the greatest distance being over 2 miles. This is rather an inconvenience to the traveling public.

Over 500 000 passenger, baggage and mail coaches come into and go out of the various passenger stations in the course of a year, this is conservative and does not take into consideration the excursions and "specials," and our idea is to do this work through the medium of a union passenger station company and, when it is completed, give its service to the different railroad companies, charging them on a wheelage basis. This would be a reduction in the terminal cost of operation to them, because it would cost them less than it does to maintain their own stations.

The question of elevating the passengers from the platforms of the train-shed to the street is rather a serious one, and the speaker has been studying the types of passenger stations throughout the United States, and the principle of the station at Columbus, Ohio, will, he thinks, be used. At that station, there is a bridge running from the waiting-rooms across the entire train-shed and from that bridge passengers descend to the platforms, practically on the plan of the station at St. Louis, with the exception that in the latter they go down first to the promenade or midway. In case the station is above the tracks, the speaker thinks that the overhead stairway is better than the subway beneath the track. We will have 30 ft. of lift. You can take a system of stairs and divide them up into flights, on the principle of the steps which led up to the Administration Building at the Louisiana Purchase Exposition, and they do not seem so long, but still 30 ft. is hard to overcome. We figure on having the waiting-rooms 3 or 4 ft. below the level of the street, and the bridge lower than the waiting-rooms, and, from there to the platforms, the descent would probably be made in three flights of stairs. Elevators will also be provided for invalids.

Howard A. Carson, M. Am. Soc. C. E., Boston, Mass. (By letter.)—Paris waited a long time for its Metropolitan Underground Railway as compared with London and one or two other cities. The road has now arrived, and the excellence of its general layout and of many of its details is too obvious to need mentioning. In visiting the work of construction in the spring of 1895, it seemed to the writer that the methods for excavation, carrying off surplus earth and other details of construction were worthy of the city in which the work was done. Mr. Carson.

Mr. Carson. M. Biette compares the later system of underground roads in London, in which each track is in a separate deep cast-iron tube, with that in Paris where two tracks are contained in a single shallow large tube of masonry, to the considerable advantage of the Paris method. Mr. Parsons makes a similar comparison to the advantage of the New York Subway. On the whole these comparisons are probably just, but there are many things to be said in favor of the London method, such as immediate full strength of structure, rapidity of advance, reduction of volume of excavation to lowest possible terms, avoidance of interference with street traffic, etc. Cast iron and machine work are cheap in London. Mr. Greathead mentioned to the writer, if memory serves, that £5 per long ton would furnish segments ready to go into tubes. Wide arches of masonry for underground roads are, of course, not claimed by M. Biette as new. They were used in the Boston Subway some years before M. Biette used them in the Paris Subway, and in London and other places at a much earlier date. It would appear that separate tubes, the cross-sections of which are nearly filled with the moving vehicles, might be made so that excellent ventilation could be obtained. The writer has not visited the latest London tubes, but was somewhat disappointed in the apparent lack of purity of the air in the City and South London and the Waterloo and City roads. In Boston, ventilating chambers with fans are provided between each pair of stations, intended to change the air about once in ten minutes. Considering the crowds that use these roads, it may be that London, Paris and New York will yet find it desirable to arrange some similar scheme.

The height and clear cross-section of the Boston Subway (about 1½ ft. greater than that in New York) were due to the fact that it was intended for trolley cars. The cross-section in the new Washington Street Tunnel (now building), although intended for cars receiving at first their current from a low-down third rail, will be made a few inches higher even than the old subway. The obvious disadvantage of this considerable height is the additional steps required to reach the platforms from the surface, the additional expense and the added danger during excavation to adjacent buildings; but there is a possibility of double-decked cars in the future, and there is also considerable likelihood that the current may be taken from a conductor on the roof rather than on the floor of the tunnel. There are two reasons for making a heavy cross-section in the Boston Tunnel; one is its considerable height, another that, in most places, there is danger that some time the roof may be heavily loaded, and that there may be an active pressure of earth on one side of the structure and an absence of resistance on the other, caused by excavations for long blocks of buildings.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DRY DOCKS.

Congress Paper No. 91.

DRY DOCKS.

By Cuthbert A. Brereton, M. Inst. C. E., London, England.

Congress Paper No. 92.

DRY DOCKS OF FRANCE.

By A. Joly, Inspecteur Général des Ponts et Chaussées,
Paris, France.

Congress Paper No. 93.

TEMPORARY DRY DOCKS FOR RAPID CONSTRUCTION.

By V. E. Timonoff, M. Am. Soc. C. E., Professor at the Institute of Ways of Communication, St. Petersburg, Russia.

Discussion of the Subject by

E. P. Goodrich, New York City, U. S. A.
Sir William H. White, London, England.
V. E. Timonoff, St. Petersburg, Russia.

Note.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

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DRY DOCKS.

By Cuthbert A. Brereton, M. Inst. C. E.

From the earliest days of shipbuilding the attention of engineers has been directed to the means by which vessels can be built, repaired, cleaned, painted and examined in the dry; and, as the size of ships increases, various methods besides the use of Dry Docks have been adopted from time to time for effecting this, according to the circumstances of the case, such as by means of:

Graving hards,
Gridirons,
Building slips and launching ways,
Patent slips,
Hydraulic lifts,
Fixed pontoons,
Floating pontoon docks.

Before proceeding to consider the larger subject of Dry Docks, it may be well to refer briefly to some of the above.

Graving Hards.—These are of ancient date, and consist of merely a flat place formed on the foreshore of a tidal river or estuary, with a coating of hard material, upon which vessels are grounded at high water and remain high and dry at low water, when any necessary repairs, cleaning and painting are effected.

This means, however, does not afford facilities for working under the bottom of vessels, and, therefore, gridirons were adopted.

Gridirons.—These consist of a framework of timber laid on the "hard," in which pits are sunk at intervals to enable the workmen to get under the bottom of the ship, and, by moving the vessel forward or backward, all parts in turn can be reached. Perhaps the largest "gridirons" constructed were those for the reception of the Steamship *Great Eastern,* at Liverpool and Milford. They consisted of a framework of four whole timber baulks bolted together and arranged so that pits could be sunk through it into the marl, and, by two shifts of the vessel, the whole of the ship's bottom, which was purposely designed to be flat, without an outside keel, was accessible for repairs, cleaning and painting.

Building Slips and Launching Ways.—These have been adopted generally for the construction and launching of ships on the banks of a river or estuary, and are usually laid more or less at right angles to the stream. The ship is built and launched in that position, but in some cases, notably that of the *Great Eastern,* where, owing to the great length of the vessel and the narrowness of the River Thames at the Isle of Dogs, where the ship was built, the ways were constructed so that the vessel could be built and launched broadside on.

Patent Slips.—Patent slips, as they are still called, are adopted for hauling a vessel out of the water for the purpose of examination or slight repairs, and, in some cases, are provided with gates at the lower end to exclude the tide at high water.

Hydraulic Lifts.—These are used sometimes in docks or sheltered places, and enable vessels to be lifted vertically out of the water by means of two rows of fixed vertical columns, with a submerged flooring between them, upon which the ship is floated and then lifted by hydraulic rams.

Fixed Pontoons.—Fixed pontoons are frequently adopted when the circumstances are favourable, the pontoons being attached to vertical fixed guides and lowered by letting in sufficient water ballast to admit of the vessel being floated upon them, broadside on. The pontoons are then pumped out, and raise the ship out of the water. This arrangement admits of almost any length of vessel being dealt with, according to the number of pontoons used, but is not convenient for executing heavy repairs, as practically only one side of the ship—that next the shore—is available at a time.

Floating Pontoon Docks.—Such docks are generally adopted in places where the nature of the foundations, or other circumstances, do not admit of the economical construction of a Dry Dock. Usually, they have tall box sides, either continuous or in sections, at intervals, fastened together at the bottom to strong cross-girders between which are placed pontoons of sufficient buoyancy, when pumped out, to lift the vessel out of the water.

These docks are provided with keel blocks and means for shoring the vessel from the sides, also, with cranes and appliances for lifting materials, and with workshops for repairs. As regards facilities, they are the nearest approach to Dry Docks of any of the other appliances for the examination or repair of vessels, and have the advantage of being able to go out to sea to meet a vessel in a damaged condition, if necessary.

One of the largest docks of this form recently constructed in England is the Bermuda Dock, which is 545 ft. long, 126 ft. wide and capable of lifting 17 500 tons. Another example, though smaller, is the dock built in 1903 for the Natal Government, for Durban Harbour. It is 475 ft. long, over the keel blocks, 70 ft. wide at the top and 61 ft. wide at the bottom. It has a lifting capacity of 8 500 tons, and will take vessels up to 23 ft. draft.

Floating docks are now generally fitted with powerful pumps, electric light, steam winches, a flying bridge to give communication across the dock, and with other appliances; and in connection with them, a floating workshop is sometimes provided, to enable vessels to be repaired at sea.

Dry Docks.—By far the most satisfactory method of repairing, painting and examining vessels—where circumstances will admit—is by means of Dry Docks; indeed, they are necessary adjuncts to any ports or docks where a considerable trade is carried on, and, owing to the large increase in the size of ships during recent years, the provision of adequate dry-dock accommodation with facilities for the rapid execution of repairs and survey has become essential.

The selection of the site for a Dry Dock involves many considerations. The size and general form of the dock are dependent upon whether it is intended for warships or for mercantile vessels, and upon the class of the latter frequenting the port, with an ample allowance for their increasing dimensions, while its position is governed generally by the nature of the foundations, the means of providing easy access from the main dock or river from which it is entered without unduly interfering with the quay or wharf space, and also by the area of ground available for the erection of workshops and the nature of the access for roads and railways.

The form and dimensions are often determined by the nature of the ground; thus, where the bottom is rock or hard marl no great thickness of floor is necessary, and it is more economical to make the dock of sufficient width to take two vessels side by side—and by the insertion of a caisson stop across the dock, with the passage placed to one side, it can be divided into two compartments so as to take four moderate-sized ships or one very long ship when required.

This form has been adopted with much success at the Barry Docks, near Cardiff, where there are three Dry Docks, one being 867 ft. long and 113 ft. wide, divided into two compartments, 336 and 483 ft. long, respectively, the width of the entrance being 60 ft. and available for vessels up to 25 ft. draft.

At Liverpool, where there are some fourteen Dry Docks, the Canada Graving Dock is 925 ft. long, 94 ft. wide at the entrance with a depth of 23 ft. of water at low neaps and 34 ft. at springs, but, as this dock is approached through the main docks in which the water is impounded, the effective depth available is from 29 to 30 ft.

At Southampton the new Dry Dock, recently constructed, has a length of 852 ft., with a width of 95 ft. at the entrance, and a depth of 37 ft. of water.

The new Dry Dock at Hebburn-on-Tyne is 700 ft. long, 111 ft. wide at the top and 90 ft. at the entrance.

The Dry Dock in connection with the new docks now under construction at Avonmouth, near Bristol, will be 850 ft. long and 126 ft. wide at the top, divided by an intermediate caisson into two compartments, 550 and 300 ft. long, respectively, with a width of 85 ft. at the entrance, having 32 ft. of water over the sill.

Commercial Dry Docks usually have but a comparatively slight batter on the side walls, and few altars, while those for warships have a more curved form of cross-section to facilitate the shoring of the heavier weights which have to be supported.

The new docks at Devonport dockyard extension are more than 740 ft. long and 95 ft. wide, while some of the later ones at

Portsmouth are 560 ft. long, 120 ft. wide at the top and 94 ft. wide at the entrance, divided into two lengths of 460 and 250 ft., with a depth of water of 44 ft. at spring tides.

The new dock at Chatham is 800 ft. long and 100 ft. wide at the entrance, with a depth of water of 33 ft.; while, at Gibraltar, three docks have recently been constructed, 850, 550, and 450 ft. in length, respectively.

The materials used in the construction of Dry Docks vary according to the requirements and circumstances of the case. Those for Government purposes are generally constructed either wholly of masonry, or of concrete or brickwork faced with granite ashlar, while those for commercial purposes are built either with masonry or concrete, as may be most economical in the district. Concrete faced with hard brickwork is now much used, and admits of rapid construction.

The entrances to Dry Docks are usually closed by gates or caissons. Gates have the advantage of being more quickly handled, but caissons are less costly, as no expensive hollow quoins, pointing sills, etc., are required.

For Government docks the older form of ship-shaped caissons is still generally used, as being more stable than box caissons when working at a light draft, but sliding caissons, which can be drawn back into a chamber, are also in use at the dockyards. This arrangement enables a railway or roadway to be carried across the dock entrance. For commercial Dry Docks the rectangular box caisson is now generally adopted as being more simple in construction.

The pumping out of Dry Docks, where the water cannot be run out at low tide, is usually effected by centrifugal pumps of sufficient capacity to remove the water from the dock in from 2 to 3 hours. These pumps are driven by steam, by gas engines, or by electricity, as may be most economical at the place in question.

Where a steam plant for driving hydraulic pumping machinery already exists near the site of the Dry Dock, steam-driven pumps are generally adopted, but, in isolated places, or where there is no steam installation near at hand, gas engines, worked either by producer gas or the town supply, are found to be economical for the intermittent work to which dry-dock pumps are generally subjected, while, if an electric installation is in existence at the docks for working other machinery, that power may be used conveniently for driving the pumps.

The drainage of Dry Docks is usually effected by side drains having an inclination to the pump-well, thus leaving the full width of the floor dry for the workmen, and, in some instances, the floor of the dock is laid on a slight incline longitudinally, to facilitate the drainage.

The necessarily limited nature of this paper prevents more than a mere glance at the many problems connected with Dry Docks, but it is hoped that some of the leading points have been sufficiently touched upon to give a basis for the discussion of this important subject.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 92.

DRY DOCKS.

DRY DOCKS OF FRANCE.

By A. Joly.*

Apparatus for the Inspection and Repair of Ships.

For a long time, in commercial ports, the repairs of ships, built exclusively of wood, and of not more than 500 tons, were made by careening them, and in tidal harbors, by banking them on a grating. But the substitution of steam for the action of the wind and of iron or steel ships for wooden vessels, caused a complete revolution in the conditions of modern navigation. The tonnage of vessels has been increased rapidly. It became necessary to furnish the important harbors with repairing plants which would make it possible to receive and dock rapidly the vessels frequenting these harbors. This has led to the construction of works of growing size and importance, for the execution of which recourse must be had to all the resources of engineering science.

These works have various forms and arrangements. Inclined slipways have been erected, sometimes normal and sometimes parallel to the shore, on which vessels of several thousand tons are raised.

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* Inspecteur Général des Ponts et Chaussées.

Several harbors are provided with works on which the vessel is first grounded and then raised by powerful hydraulic presses.

In fact, the only plants which are generally utilized at present for very large vessels, are floating docks and graving, or dry docks.

Comparison of the two systems caused an interesting discussion at the last International Congress of Navigation, held at Düsseldorf in 1902. The question of choosing between them was then in order in Germany. The Vulkan Company of Stettin had just built a large floating dock capable of receiving vessels of 11 000 tons displacement, and MM. Blohm and Voss had put in service a floating dock of 17 000 tons displacement at Hamburg. On the other hand, a large dry dock had been built at Bremerhaven and two dry docks, also of very great dimensions, were under construction at Kiel.

The Congress concluded that if the plant is to serve for the general benefit of navigation, the dry dock is almost always preferable, "in view of the qualities of simplicity, durability and safety which it offers," and that when it must act as a private plant and yield immediate profit, the floating dock, which costs less and can be built more rapidly, may prove to be more advantageous.

Dry Docks in Use in France.

Only old floating docks of very small importance, and some inclined slipways which are owned by private companies, or chambers of commerce, can now be found in France. All plants for repairs which exist in commercial harbors consist of dry docks which, except at Marseilles, have been built by the State.

French dry docks do not present any special characteristics. They generally have a concrete foundation with floor and side walls of masonry. The inner floor has either a central drain, or more generally, two lateral drains sloping transversely from the central axis. A rudder pit is almost always provided at one end of the floor. The head walls are sometimes vertical and sometimes have a batter of one-third, as at Dunkirk, or of six-tenths, as at Marseilles. In the interior the side walls form steps, the number of which varies from 1 to 4 and is generally 3 in large docks. These steps are from 0.80 m. (2.62 ft.) to 1.20 m. (3.94 ft.) wide. Slide-ways to let down timber have been provided in a certain number of dry docks.

All docks are closed by caissons serving as gates. Generally two recesses for the gates are provided at the head. In a small number of docks the second recess has been placed at a greater or less distance from the entrance, so as to be able either to reduce the dimensions of the dock, or to place two vessels in the same dock, if two caisson gates are provided. The culverts for supplying the required water are placed at the heads of the majority of the new docks. The caisson gates are provided, besides, with water ducts by which communication can be established between the exterior and the interior. The keel blocks of several docks are made of cast iron with a top piece of oak.

Caisson gates are arranged in various ways; in all cases they approximate two types which have been studied, the first at Cherbourg for tidal harbors, and the second at Toulon for harbors without tides, and which can be used for docks discharging into a basin or wet dock. The latter type is the one most used. Formerly the caissons were given complicated forms approaching those of the vessels. The present tendency is more and more toward simple geometrical forms, which permit of easier and more economical construction, and which make the computations of their resistance less laborious.

The drainage of the dock is everywhere effected by centrifugal pumps and compound steam engines. The pumps are placed on a floor intervening between the pump-well and the earth-fill. The engines are placed sometimes in the same chamber as the pumps and sometimes on the upper floor. In the latter case the transmission of motion was effected formerly by belts; at the present time, the pumps have a vertical axis and are connected directly with the engines. The required capacity of the pumping machinery is computed generally on the basis that under the most unfavorable conditions the dock should be emptied in 3 or 3½ hours.

Work Done in France Since 1890.

The methods of construction adopted for the following dry docks built, or improved in France during recent years, will now be described: Dry Dock No. 4 at Dunkirk, completed in 1889, and which, until 1900, had been the longest in use in France; Dock No. 4 at Havre; the new docks at Brest, Bordeaux, and the military harbors; the dock of Missiéssy at Toulon and those of Pontaniou at Brest.

Dry Dock No. 4 at Dunkirk.—Dock No. 4 at Dunkirk has been built with two entrances, one from the outer harbor and the other from Tidal Basin No. 2 of the Basin Freycinet. The main object of this double entrance was the utilization of the dock as a lock in case the only lock of the basin should not be in working order. The dock has, therefore, two entrance openings, each provided with two sills and face posts for caisson gates, with symmetrical faces 1.00 m. (3.28 ft.) apart, and so disposed that the caisson will assure a tight joint in whatever direction the pressure of the water may be exerted.

The soil on which the dock is erected consists, for an indefinite depth, of a very fine sand which does not compress but flows when saturated with water. The foundation consists, generally, of a layer of concrete 203 m. (666 ft.) long, 37 m. (121.4 ft.) wide and 2 m. (6.56 ft.) thick, deposited in a depth of water of 1.00 m. (3.28 ft.) maintained in the excavation.

Lengthening of Dry Dock No. 4 at Havre.—Dock No. 4 at Havre was built in a pit which was excavated at the same time as the Eure Basin. The soil on which it rests consists of sand mixed with clay, and is easily undermined. The foundation consists of a general layer of concrete which is lowered to an elevation of —5.44 m. (—17.8 ft.) and is covered in the dock by a brick pavement. The walls are made of silicious ashlar-work with facing of bricks. A large caisson sunk by compressed air was used. The caisson had a length of 48.50 m. (159.1 ft.) along its axis, a width of 38.45 m. (126.1 ft.) and a surface area of 1 420 sq. m. (15 270 sq. ft.) It was erected on the site which it was to occupy finally, after excavating the soil, removing the old masonry down to an elevation of 4.00 m. (13.1 ft.) and making an embankment up to the same level in the half-circle of the dock. At the same time the caisson was sunk, the sill of the entrance recess was recut, and one of the wing-walls of the dock, the mortar of which had become decomposed, was rebuilt by the aid of compressed air. These various works, which continued for 34 months, were completed at a cost of 1 575 000 francs.

The New Dry Dock at Brest.—The new dry dock, 225 m. (738.2 ft.) long, which is under construction at Brest, is being erected in the dry, behind an earthen dam which separates it from the adjacent basins. The soil consists of clay, more or less compact, covering a layer of gneiss which has been found at an elevation of about —10.00 m. (—32.8 ft.).

The soil has been excavated for the whole area required, down to zero elevation. The sills of the entrance openings and the side walls rest directly on rock by means of masonry shafts built in the excavation and sunk by excavating from the inside. The shafts are of the following average dimensions: height, 10.00 m. (32.8 ft.); outside dimensions, 6.00 by 6.00 m. (19.7 by 19.7 ft.); thickness of masonry, 2.00 m. (6.6 ft.) with a reduction to 1.0 m. (3.3 ft.) at the bottom. The interior hollow space is fitted with cement concrete up to an elevation of —6.50 m. (—21.3 ft.) and with masonry above this level. The shafts are 1.0 m. (3.3 ft.) apart, and the space between them is filled with masonry built by means of sheet piling.

The Dry Dock at Bordeaux.—The new dock under construction at Bordeaux is 40 m. (131.2 ft.) distant from the existing dry dock. It has a width of 16.0 m. (52.5 ft.), an effective length of 100.0 m. (328.1 ft.) and is of no special interest except for the method of construction adopted for it. The soil on the site, down to an elevation of about —6.0 m. (—19.7 ft.), consists of a clayey mud and below that to an elevation of —12.0 m. (—39.4 ft.) of layers of sand, containing more or less gravel. Below the sand an extremely compact layer of clay is found.

The side walls and the entrance sills of the present dock were founded by means of excavated shafts; the shafts were generally 9.75 m. (32.0 ft.) long, 8.0 m. (26.2 ft.) wide and 9.0 (29.5 ft.) high. They were built in an excavation pumped out, after excavating the sand, to an elevation of —1.2 m. (—3.9 ft.) and rested on the layer of gravel. The floor was made of a layer of concrete laid down to the gravel after the excavation had been made inside of the enclosure formed by the shafts.

The new dock opens into the wet dock, and to build it a portion of the west quay wall of that dock had to be taken down. The method of construction which has been decided upon for the dry dock is the one which MM. Zschokke and Terrier had adopted for the dry docks at Genoa, and which has been used more recently for the docks at Kiel. This method consists in dredging the pit down to the depth at which the structure will rest, and then building under compressed air, by a movable caisson, blocks of masonry placed side by side. The intervals between the blocks of each course are filled when the upper blocks are begun, the latter being set so as to break joints. In this way the floor and side walls of the dock have been built and the wall, connecting with the adjacent quay, has been completed.

The masonry block, which is to serve for the erection of the well for the pumping machinery, is founded on a fixed caisson. The pit rests on a bank of gravel dredged to —7.20 m. (—23.6 ft.) with a depression to —8.50 m. (—27.9 ft.) under the rudder pit. The pit, which has a volume of 100 000 cu. m. (130 800 cu. yd.), has been excavated with a slope of 3 to 2. The foundation has a length of 116.5 m. (382.6 ft.) and a width of 27.7 m. (90.9 ft.). The caisson used in the construction of the floor has a length of 30 m. (98.4 ft.), a width of 7.5 m. (24.6 ft.) and weighs 112 tons; the working chamber has a height of 2.0 m. (6.6 ft.). The ballast consists of a layer of concrete and pig iron.

The following structures have been established in military harbors:

Harbor of Toulon: The Dry Dock at Missiéssy.—The Harbor of Toulon has three groups of dry docks. The last group called Missiéssy consists of two docks built by M. Hersent from 1878 to 1881, and is 25 m. (82.0 ft.) wide at the entrance and 133 m. (436.4 ft.) long.

In 1893 the construction of a third dock was decided upon. It is to be of the same width and 150.0 m. (492.1 ft.) effective length, and competitive bids have been opened for its construction. The soil at the site of the projected dock is known in that region as "safre," and consists of pebbles of all sizes mixed with a cement of a partly clayey and partly sandy character; this soil is very resistant but quite permeable. It is flooded by fresh water coming from the very high calcareous hills which surround Toulon.

M. Hersent undertook to construct the dry dock in a single caisson by aid of compressed air, according to the procedure which he had adopted for Docks Nos. 1 and 2, for the contract price of 4 087 640 francs. According to this system the pit in which the structure is to be erected is excavated by dredging, and at the same time the caisson is being built. The caisson is floated and ballasted with masonry, and is then brought to the site which it is to occupy. The ballasting continues by building the side walls until the caisson rests on the bottom of the pit. A sufficient overload is added to make sure that the caisson will not be uplifted by the compressed air in the working chamber. This chamber is filled with concrete after the foundation has been thoroughly prepared for it.

The entrance sill is 9.35 m. (30.7 ft.) below low-water level; the entrance opening has a width of 25 m. (82.0 ft.) at this level and of 28.84 m. (94.6 ft.) at the level of the coping course. The caisson used by M. Hersent had a total length of 185.8 m. (609.6 ft.) and a width of 41.0 m. (134.5 ft.); its area covered 6 500 sq. m. (69 967 sq. ft.). Its frame consisted, between the exterior walls, of deep transverse girders, twenty in number, descending to the cutting edge. These girders were 8.04 m. (26.4 ft.) apart from center to center and had at the middle a depth of 4.43 m. (14.5 ft.) for a length of 13.67 m. (44.8 ft.), getting deeper toward the outer walls, where their depth reached 6.70 m. (22.0 ft.). They were connected above the roof of the working chamber by four longitudinal beams having their upper chords on the same plane as those of the transverse girders. Of these four girders, the two intermediate ones were placed 6.3 m. (20.7 ft.), center to center, and the two end ones, 1.5 m. (4.9 ft.) from the side walls. The framing of the roof of the working chamber between the large longitudinal girders was of lattice girders 0.95 m. (3.25 ft.) deep. The planking was laid 7 m. (23.0 ft.) above the cutting edge with thicknesses varying from 5 to 7 mm. (0.2 to 0.28 in.). The weight of the caisson was 1 924 000 metric tons.

The caisson was put together in an open trench in proximity to the dock site, and during 8 months was lowered to 2.2 m. (7.2 ft.)

above low water. The water-line was 0.25 m. (0.82 ft.) above the plane of the ceiling. First, water was admitted into the trench to prove the tightness of the joints, then, after the repairs required on the joints and the riveting had been effected, the trench was filled again with water, and, after the perfect tightness of the caisson had been proven, it was towed into the adjacent tidal basin and the ballasting was begun, February 27th, 1896.

The process of ballasting the caisson was the most delicate part of the work. The water being always calm, a new layer of sheathing was only put on when the projection of the coffer-dam above the water was reduced to 1.0 m. Ten courses were thus built successively, the total weight of the coffer-dam being 274 000 metric tons. At the same time the coffer-dam was raised, the iron coffer-dam was built. This was intended to separate that portion of the structure which corresponds to the entrance gate from the sea. The bottom of the coffer-dam was placed on six iron brackets set at 6.0 m. (19.7 ft.) below the level of the cutting edges. The walls were computed to resist the water pressure. For the sake of precaution, however, they were reinforced by iron brackets surrounded by masonry and by timber struts. The interior of the coffer-dam was filled with water almost to the middle of the wetted height.

When the caisson reached a depth of 1 m. above the bottom, it encountered a layer of fluid clay sufficiently impermeable to stop the downward motion of the caisson, notwithstanding a considerable increase in the load. Holes had to be made in the walls of the working chamber to facilitate the escape of the water. From this moment the downward movement proceeded regularly to the elevation —15.9 m. (—52.2 ft.), to which the pit had been dredged previously.

An important change was made in the original plans during construction by deciding to lengthen the dock 25 m. (82.0 ft.). The lengthening was accomplished by a caisson separated from the first one by a distance of 1.25 m. (4.1 ft.). This caisson had a length of 23.75 m. (77.9 ft.), a width of 41 m. (134.5 ft.), and was built on a launching slip placed on the beach near its final position. It was mounted on three longitudinal slide-ways supported by short piles. The launching operation presented serious difficulties, due to the settling of the slide-ways. The ballasting of this second caisson and the filling of its working chamber was accomplished by following the same procedure as for the large caisson. The work on it was begun June 10th, 1897, and completed on November 30th, following.

The entire work on the dry dock, which was begun September 1st, 1894, was completed in September, 1898, two months before the time contracted for. The amount paid to the contractor amounted to 5 014 683 francs. The cost of the iron caissons figures in the latter amount for a sum of 1 043 000 francs for the large caisson, and 243 000 francs for the small caisson. The work proved to be a complete success. It was a daring operation, which does credit to the able contractor who designed and executed it, to sink, with a depth of water of 16 m. (52.5 ft.), a caisson with an area of 6 500 sq. m. (69 967 sq. ft.) loaded with 100 000 tons of masonry.

Dry Dock of Pontaniou at Brest.—At Brest the two dry docks of Pontaniou, which were the largest in the harbor for a long time, have just been reconstructed. These docks have effective lengths of 153.0 m. (502.0 ft.), widths of 16.4 m. (53.8 ft.) and 19.4 m. (63.6 ft.) at the bottom with sills at elevations of 1.7 m. (5.6 ft.) and 0.57 m. (1.9 ft.). They have been lengthened, widened and deepened. The new entrance openings have widths of 19.0 and 25.0 m. (62.3 and 82.0 ft.) with sills at elevations —3.3 m. (—10.8 ft.) and walls battered 1 to 4.

General Remarks on the Dry Docks in France.

The following remarks may be formulated as conclusions based on the experience obtained from the dry docks erected in France and more particularly from the work accomplished during the last decade in improving old docks and constructing new ones.

Not considering the oldest dry docks erected in the Harbors of Havre, Saint Nazaire and Marseilles for regular passenger service between France, America and the Far East, the majority of dry docks built in French harbors were included in the programme of great public works laid out in 1878. The designs of these docks had been studied with regard to the conditions of commercial navigation at that time and the consideration of such increase in the dimensions of vessels as it then appeared prudent to take into account. Indeed, the previsions considered ample twenty-five years ago will probably become insufficient in the near future, if the tendency to build larger and larger merchant vessels, which has obtained for several years, does not change. The 25.0-m. (82.0-ft.) dry dock at Saint Nazaire, which has been lengthened, and the dock at present under construction at Brest will be the only ones able to receive the great transatlantic steamers which have been built recently in England and Germany.

It appears that, for the future, it would be prudent to assume for harbors intended to receive a large, regular traffic with America and the Far East, dry docks with a least width of 30.0 m. (98.4 ft.) and lengths capable of being extended to 300 m. (984.3 ft.) with a draft of 10.0 m. (32.8 ft.) of water at high water.

Almost all the dry docks in use in France furnish very satisfactory service. The caisson gates are easily handled everywhere. It has not seemed, up to the present, advantageous to introduce rolling gates like the gate of Prince's Dock at Glasgow. It is only in special cases that the latter arrangement, which is more costly, may be preferable to floating gates of the usual type. The pumping machinery, which assures the emptying of most of the new dry docks in from 3 to 3.5 hours, appears to be sufficient; there is no serious reason in most cases for attaining a more rapid drainage.

Wherever possible, it was sought to carry on the work of construction in drained excavations. The comparatively recent dry docks at Dunkirk, Calais and La Pallice have been built at the same time as the adjacent basins in one great excavation.

As a whole, no novel method of construction has been resorted to in recent years in the building of dry docks, but the applications which have been made deserve to be described because of their importance. The use of separate piers for the foundation of the side walls and apron, as of the great dock at Brest, has been customary in France for a long time. This mode of construction permits sinking the foundation to great depths in muddy grounds without excessive cost; it is, however, toublesome to increase the number of joints for a dry dock. It may also happen that, if the soil is compact, the piers will sink with difficulty, and if the mud is soft and of variable composition, they will lean out of position; finally, if the rock, on which they must rest, slants off rapidly, the completion of the sinking process becomes extremely laborious.

The use of a coffer-dam made of large caissons, like the one which was proposed at Toulon for Missiéssy Dock No. 3, and which has been applied to the foundation of various locks, and which is to be used for the dry dock at Dakar, furnishes a solution which is more expensive, but which is more expeditious and less uncertain. When a large dock has to be built in water the execution of the work is always a very delicate operation. For the last 25 years the method of building a concrete coffer-dam around the work, which for 50 years before was used quite generally at Toulon, has not been used in France. Several accidents happening to the floors, which were raised by the action of pressure, caused by powerful artesian springs under them, have made the use of compressed air preferable, notwithstanding the increased cost which results therefrom. Three very important applications of compressed air have been made during recent years.

The sinking of a large caisson of 30.5 m. (100.1 ft.) at Havre shows that the largest dry docks can be built according to the usual methods by using transverse caissons sunk side by side. The joint between the caissons is the weak point of the construction; experience, however, has shown that with sufficient care an absolutely tight joint can be obtained. Sinking by the usual methods has the advantage of allowing the various caissons to be sunk to different depths according to the character of the foundations.

For a homogeneous soil the use of a single caisson, in which all the masonry of the dock can be laid in the dry and in open air and the concrete in the working chamber under compressed air, is a very practical solution, as has been proven by the complete success in the construction of the three Missiéssy Docks.

Objections have been made on the other hand that troubles may arise because of embedding a considerable amount of iron in the mass of masonry. But the behavior of Docks 1 and 2 at Missiéssy for the last 25 years and the extended experience since that time with conditions under which iron embedded in cement is preserved, have been such as to remove all fear which may arise in this respect.

The use of a floating caisson, which was adopted at Paimbœuf and afterward at La Pallice for building quay walls, and which has recently been utilized at Genoa, Kiel and finally at Bordeaux for the construction of dry docks, permits the execution of the whole work by compressed air without leaving any trace of iron in the completed masonry.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 93.

DRY DOCKS.

TEMPORARY DRY DOCKS FOR RAPID CONSTRUCTION.

By V. E. Timonoff,* M. Am. Soc. C. E.

General Considerations.

As maritime commerce extends to the most remote regions of the world, the need of finding everywhere facilities for thorough repairs of damaged merchant vessels makes itself more and more felt. Many vessels have had to be abandoned because there were no facilities and appliances for their repair at nearby landing places. This happens less frequently with warships, but even the navies of the world may sometimes be in need of repairs when far from harbors with special and permanent repairing facilities.

On the other hand, modern appliances for repairing ships are very costly and cannot be installed everywhere. It is therefore of interest to try to find whether the same object can be attained by more simple and less costly means, though less conveniently than with perfect facilities.

It is the object of this paper to indicate one of the possible solutions of this problem. The method proposed by the writer seems to him to promise satisfactory results should local conditions permit its application.

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* Professor at the Institute of Ways of Communication at St. Petersburg, Russia.

The Repairing of Ships in Harbors Provided with Docking Facilities.

In commercial or military ports various means are used for important repairs to floating ships, for scraping the hull, for repainting, etc., according to each case, and, especially, according to the dimensions and importance of the vessel. These are accomplished either by heaving the ship down or grounding it on a keeling dock, by raising it on a lifting slip, by towing it into a repairing or floating dock or, finally, by lifting it by an elevating apparatus. The appliances for repair most generally used and best adapted to vessels of all dimensions are dry docks. They consist, as is well known, of fixed basins, which can be emptied and so maintained after the vessels have been brought into them. The construction of dry docks generally presents serious difficulties because of the pressures to be sustained and the tightness required.

A stiff floor and side walls are built, which form on the inside a succession of banks or steps to facilitate the propping of the vessel. Stairways and slide-ways are provided for the easy access of the workmen and materials. Capstans, mooring posts, tackle and all kinds of appliances are placed to allow of easy handling of vessels and caissons, and, finally, derricks are arranged for managing heavy pieces such as screws and shafts.

The water in the dock, whether due to infiltration or filling, is collected in drains and led by conduits into drain wells from which it is pumped into the sea. The ships in the dock rest on keel and bilge blocks and are supported by props and shores. To allow space for the rudder while the vessel is in the dock, a pit, called the rudder-pit, is frequently made in the floor.

The location of docks is so determined that vessels may be able to enter with safety and security, as the operations of entering and leaving, especially with large ships, are quite delicate. The docks are, therefore, placed not far from the quays where the ships are usually stationed.

Dry docks, entrances to which are not provided with mitered gates, are closed either by floating caissons or by caissons rolling on the floor of the dock. A floating caisson acts as a movable and tight screen, which can be floated to uncover the opening it closes, and which can be raised and lowered by admitting water into the floating chamber. It is brought into the dock and depressed before the dock is drained; after the emptying of the latter it is raised by discharging the water used in lowering.

The writer has enumerated the principal features of an ordinary dry dock to show in a stronger light the simplifications which he proposes for temporary dry docks.

The Repairing of Ships without Docking Facilities.

If the repairs to be made on a ship are not very considerable, and if the damaged parts are not too far from the line of flotation, the repairs can sometimes be made successfully while the ship is afloat.

By displacing the ballast on the vessel the damaged portion can be raised above the surface of the water and the repairs be made. This method is applicable within very narrow limits only, so much the more so since an unsymmetrical load on large vessels, especially on warships, is often dangerous and may cause their overturning.

Sometimes it is possible to surround the damaged part by a floating caisson which fits snugly against the sides of the vessel and permits of keeping the place to be repaired partly dry. Work in such caissons is naturally slow and inconvenient. The limited dimensions of the caisson do not permit the easy introduction of plates. Besides, the shape of certain parts of a vessel does not lend itself to the use of a floating caisson, and, if the damaged parts are deep, the pumping becomes very difficult, if not impossible.

Finally, the building of the caisson itself is complicated, laborious and slow work.

In tidewater unimportant damages can be repaired by stranding the ship on a sand bank at high tide and so exposing part of the vessel at low tide. This method is applicable only when the damaged part is located between the high and low water levels.

Without proceeding further to examine the various expedients which may in certain cases give good results and not be applicable in others, it must be admitted that the universal method which is able to meet all conditions is the dry dock. By giving access to all parts of the vessel, it makes possible the concentration of a great number of workmen at the place of damage, permits the handling of plates and other parts of all dimensions, and, finally, insures continuous and safe work.

NECESSITY FOR THE RAPID CONSTRUCTION OF TEMPORARY DRY DOCKS.

The somewhat hasty examination of methods employed in repairing ships afloat will, however, suffice to show the necessity there may be for the rapid construction of temporary dry docks, in the interest of the merchant marine as well as of war vessels. With this in view, all indispensable work must be reduced to a minimum, and any parts of a dry dock existing in one form or another in the given locality must be utilized to the fullest extent.

If a natural or artificial basin can be found where the dry dock can be located, the excavation of a special basin may be dispensed with. If pumps are available sufficiently powerful to maintain the dock in a condition dry enough for continuous work in spite of more or less considerable infiltration, it will not be necessary to secure a perfectly impermeable floor and side walls, and the least required tightness will suffice.

It will be unnecessary also to surround the dock with walls more or less vertical so that walls of loose stone only, without mortar, may be used, which can be laid in place by unskilled labor and by means of cars and boats. The blocks, which in the ordinary dry dock support the weight of the vessel and require a very solid foundation to transmit it to the ground, can also be omitted, as will be shown later. Finally, the floating caisson may be replaced by a gate of a rougher kind and easier construction.

The problem of building a temporary dry dock, undoubtedly, has several solutions for each special case encountered by the engineer, and it is far from the intention of the writer to enumerate all methods by which a dry dock can be rapidly constructed. As stated above, he merely desires to indicate a method proposed by him for a particular case and which appears to be extremely simple and cheap.

A SYSTEM OF TEMPORARY DRY DOCKS FOR RAPID CONSTRUCTION PROPOSED BY THE WRITER.

The fundamental idea of the system of temporary dry docks proposed by the writer is based on the reservoir dams as built of

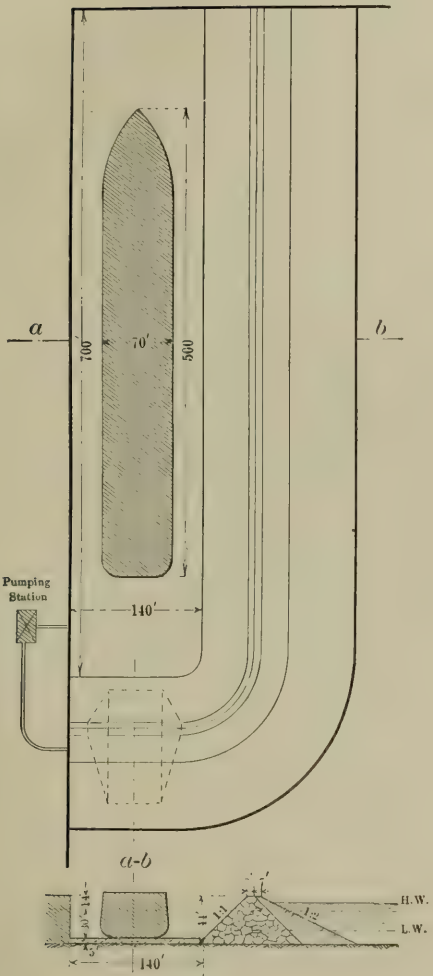


FIG. 1.

loose stones in California. These dams, as is well known, have been invented by practical men without technical training but gifted with the genius of their race. The pioneers of civilization in the gold mining State needed great stores of water. To build dams in the rocky gorges of the mountains nothing but stone was available. The use of mortar for binding the stones together was impossible because of the lack of cement and skilled labor. It was then attempted to build reservoir dams of stones thrown on the ground as riprap without mortar and, from the point of view of rapid work, cheapness and strength of the dams, remarkable results were obtained. A dam 210 ft. high, exceeding in height the greatest dams built of masonry laid in cement mortar, is now being built of loose stone in California. The possibility of building walls of loose stone, able to resist such high water pressures, enables us also to use this method of construction for dry docks.

In an existing basin, or near a shore sheltered from the waves, or, finally, in a recess of the ground, an enclosure is made by means of a dike of loose stones. Figs. 1 to 4 indicate the different cases which may occur according to local natural or artificial conditions. This dike consists of a stone prism and is covered from the outside with a layer of earth to increase its tightness. Such a dam, compared with any other kind, has the following advantages:

1.—Rapid Construction.—The stones are dropped just as they are brought to the work without sorting and without mortar, and, as they can be transported in cars or boats, the working space can be enlarged almost at will and the number of workmen, who may be unskilled laborers, may be correspondingly increased. A speed of construction is obtained with such a loose stone dam which cannot be reached with any other materials. If, for instance, the dam had to be built of sheet-piling and stones, timber of large dimensions and special pile drivers would be required; it would further be necessary that the ground should permit the driving of sheet-piling all around the dam, and, if all these conditions were fulfilled, rapid work could not be done without risking the tightness of the work.

2.—The Tightness of a Loose Stone Dam Can Be Progressively Increased According to the Needs.—A loose stone dam covered with a layer of earth can be made tighter by simply increasing the

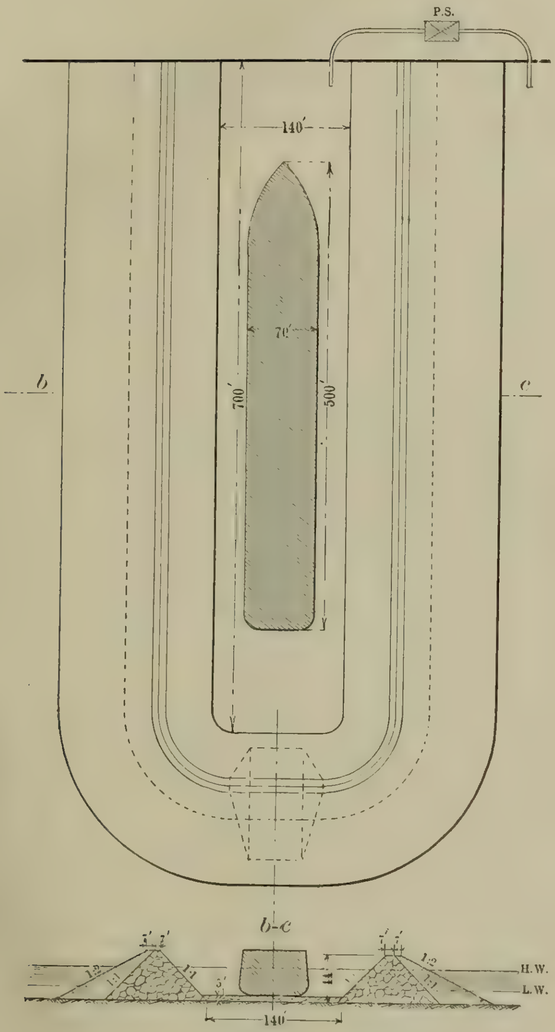


FIG. 2.

thickness of the protective layer. In all other systems the dam must from the start have such dimensions as will secure the necessary tightness, which leads to exaggerated dimensions which cannot be determined from the beginning. A loose stone dam covered with earth is built of the least dimensions, and afterward, according to the indications of its working, the thickness of the earth layer can be increased, if required, without exceeding the necessary limits.

3.—Easy Removal.—To remove a loose stone dam or to make an opening in it, unskilled laborers supplied with wheelbarrows for the upper portion and a dredge for the lower will suffice. Into the enclosure made by a dam as described and having a sufficient depth of water a vessel can be floated through an opening left in the dam for this purpose. This opening is then closed in the way the dam was built or by more perfect means.

A pumping station located on the shore or on the dam will accomplish the draining of the dock and the lowering of the vessel. To protect the hull from damage which may be caused by resting the vessel on the ground, a deep layer of sand is deposited on the bottom of the dock. This layer of sand replaces the blocks of the ordinary dry dock. As the water falls, due to the action of the pumps, the vessel gradually compresses the sand and thus prepares the bed for supporting its weight. This is distributed with much regularity over a very great area.

Actual experience in stranding war and merchant vessels of high tonnage on sand banks exposed at low tide, to make urgent repairs, has proved that the strength of the hull is not impaired by this expedient. This has not been tried with large modern vessels of more than ten thousand tons' displacement, but even for vessels of such dimensions there is no reason to expect that serious trouble will be caused by their resting on a layer of sand instead of a series of blocks. Such trouble will be of small importance since the repairs generally required are not far from the line of flotation. It will, therefore, not be necessary to drain the dock completely; it will suffice simply to lower the water level enough to uncover the damaged part. The sand foundation will thus, in such cases, have to sustain only a fraction of the weight of the vessel. For damages located deeper, it may be equally unnecessary to drain the dock completely, but it may suffice to lower the water level enough to

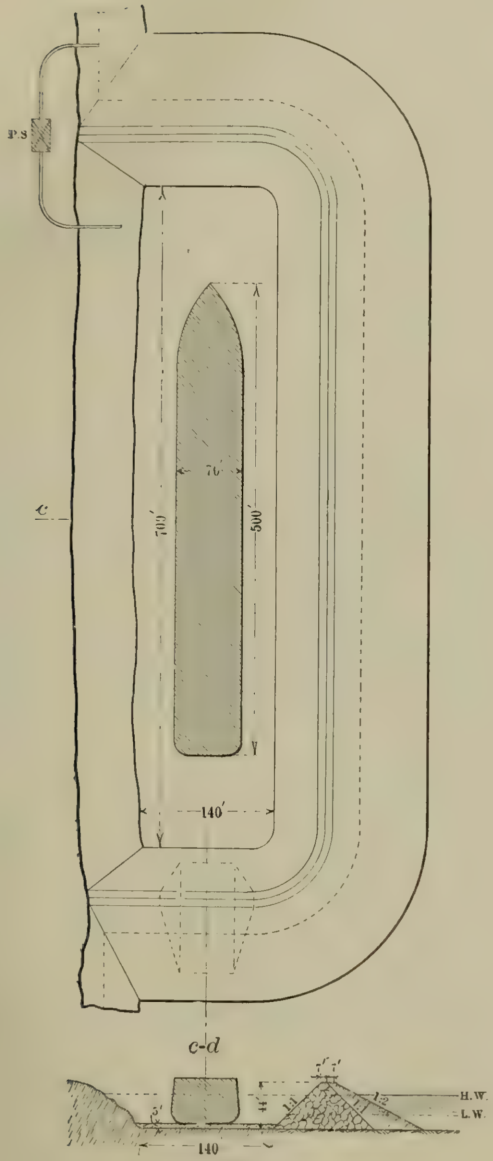


FIG. 3.

make it possible to build around the damaged spot a sand dam and then to drain this secondary enclosure.

To float the vessel out of the dock after repairing, an opening is made in the dock of sufficient size to let the vessel pass. In a dam of loose stone and earth this work is very simple. The method of procedure has been indicated above. The amount of material to be removed can be reduced to a minimum by floating the ship out at high water. Had the dam been built of piles and sheet-piling, these would have to be removed for their full height without being able to utilize the advantages of a high tide. The dam can be closed again for new repairs just as easily.

If the temporary dock has to be used frequently enough, and if sufficient time is available to build a more perfect gate, this can be done while the dock is in use. This object could be attained, for example, by the construction of a gate with the aid of wooden caissons. It can be built in a separate place and be put rapidly into position without stopping the work in the dry dock for a long time. To close the entrance of the dock, a boat of convenient dimensions may be adapted, which, while not being as perfect as a real floating gate, will much facilitate the handling of the opening and closing of the dock and still give sufficient tightness.

As a final improvement a floating or rolling dock gate may be built, and, should it be found necessary, blocks to support the weight of the vessel may be built on special foundations.

The Application of the Proposed System.

The temporary dry dock for rapid construction, proposed by the writer, consists, as described in the above, of an enclosure made partly by the shore, natural or artificial, and partly by a dam of loose stone and earth. It can be emptied and kept dry by a pumping station working continually, if required. The function of the keel blocks is performed by a deep foundation layer of sand. The opening through which the vessel is floated into the dock is closed by a fill of loose stone and earth which is afterward removed by simple means to let the repaired vessel out. A dock of such construction can be improved further without stopping the work in the dock.

The successful application of this system of construction de-

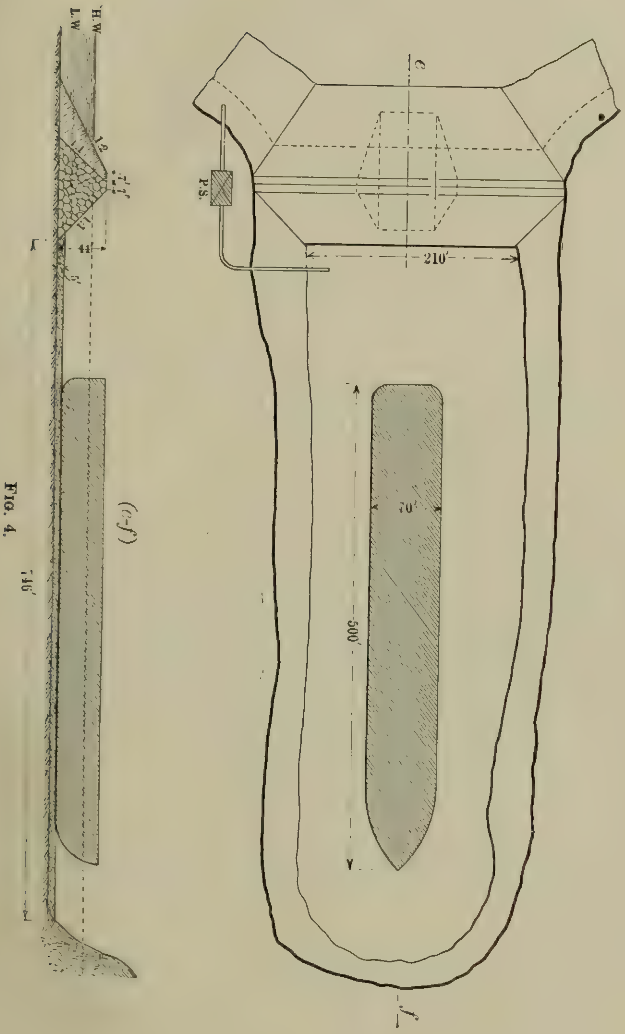


FIG. 4.

pends on the character of the ground. If the ground is too permeable, if it is a fissured rock, and if, therefore, the natural bottom of the dock may be liable to very considerable infiltration exceeding the pumping capacity, the difficulties to be overcome are very great. But in the majority of cases the same conditions will be encountered, as far as pumping is concerned, as in the sinking of large trenches, and the success of the enterprise cannot be endangered.

The location of the dock should be so chosen as to make the perimeter of the dike and the amount of work to be done as small as possible. If the shore forms a bay in which the water is deep enough or can be easily deepened it will preferably be chosen. See Fig. 4. If not, there may be a corner of a floating dock (Fig 1), or a site near a sheltered shore. These conditions are, however, of a character which cannot be generalized. Tides can facilitate the use of the proposed system by making possible considerable reductions in the volume of the dam to be removed to let the vessel out after repairs have been completed.

Conclusions.

Merchant vessels are always, and war vessels are sometimes, in need of repairs of damages sustained by them far from ports provided with all modern facilities for docking and repairing. A dry dock is the most convenient appliance for repairing. Means should be devised to construct dry docks rapidly and cheaply, with materials which may be at hand, at localities distant from the centers of production. The dry-dock system proposed by the writer, consisting of a dam of loose stone and earth and a sand foundation replacing the blocks, seems to fulfil, for local conditions where it is applicable, the requirements of quick construction, simple work and cheapness, while it procures for vessels the facilities to make all necessary repairs.

It is the wish of the writer that this paper may serve as a basis for a discussion at the Congress, and that this discussion may throw light on the very important subject of repairing vessels damaged far from ports provided with all facilities for this purpose.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON

DRY DOCKS.

By Mr. E. P. Goodrich, Sir William H. White and
Prof. V. E. Timonoff.

Mr. Goodrich.

E. P. Goodrich, Jun. Am. Soc. C. E., New York City.—In "Lloyd's Register of British and Foreign Shipping" for 1904-05, Vol. 2 (copy of which was courteously furnished the speaker for use in connection with this discussion), there are listed, in the United States, both on the seaboard and on the Great Lakes, 191 different arrangements for the examination and repair, in the dry, of vessels of all sizes. The whole of North America, including the West Indies, Mexico, Canada and United States, on both seaboard and Lakes, is credited with 252, while Europe has 981.

The "Blue Book of American Shipping," 1904, gives numbers somewhat larger for North America and the United States, but not materially so.

Of the list of devices mentioned by Mr. Brereton, there are in the United States, according to Lloyd's, the following numbers:

Graving hards	0
Gridirons	0 (5 in Canada)
Building slips and launching ways	(not listed)
Patent slips (including marine railways)	71
Hydraulic lifts	1
Fixed pontoons	0
Floating pontoon docks (balance, sectional, etc.)	66
Dry docks	50

r. Goodrich.

Besides these, there are mentioned a coffer-dam, and various bow and stern docks, the latter being nothing more than special coffer-dams, built nearly to the shape of the ship's bottom, capable of being floated into place, and then pumped out, thus exposing only small portions of the vessel's hull, while she remains afloat.

The percentages of graving and of floating docks in North America, the United States, the United Kingdom and Europe, as shown in Table 1, are of interest.

TABLE 1.—PERCENTAGES OF GRAVING AND FLOATING DOCKS IN NORTH AMERICA, THE UNITED STATES, EUROPE AND THE UNITED KINGDOM.

Locality.	Total Means.	Percentage on the Continent.	Graving docks.	Percentage of total.	Floating docks.	Percentage of total.
North America	252	....	64	25	73	29
United States	191	75	50	26	66	35
Europe (including United Kingdom)	981	....	451	46	91	9
United Kingdom	489	50	268	56	13	3

Graving hards and gridirons are quite numerous abroad, but, in the United States, the only thing which approaches a graving hard, of which the speaker knows, is the Cob Dock at the New York Navy Yard, now long since disused for the purpose. The eddy formed by a sudden turn in the East River caused the formation of a hard knoll or "cob," and it is said that in former times captains of merchantmen grounded their vessels on this "cob" at high water and took advantage of the falling tide to examine and clean the bottom, even careening the hull, more than caused by the falling water, by tackle attached to the masthead. This operation was called "cobbing," but it is impracticable with modern vessels on most shores of the United States, because of the small range of tides.

Marine railways differ little in different localities, and, in late years, few improvements have been made in their construction, when compared with those in use a decade ago. The speaker has been connected with the construction of a small one for yachts, however, in which the power was derived from an alternating-current motor attached to a winch with a special automatic power-brake, and with special backing apparatus for launching the cradle when necessary. The installation has proved eminently successful, and exceedingly economical of power (the hauling of a 300-ton vessel costing but 40 cents for power, the speaker has been told). There is no reason why the above-described details of construction cannot be applied to vessels of more than 300 tons displacement.

Mr. Goodrich. The screw lift at Barbadoes may be mentioned as an example of a type similar to the hydraulic lift described by Mr. Brereton. It has a capacity of 1 200 tons, was built in 1892, and will handle vessels drawing 14 ft. of water. In 1776 such a lift was in operation in New York City.[*] This dock consisted of a cradle into which the ship was floated, the cradle and ship were then raised by screws attached to the cradle and bearing upon the tops of piles.

The only hydraulic lift in the United States, as far as the speaker knows, is that belonging to the Union Iron Works, at San Francisco, and constructed by that company. It has a capacity of 4 000 tons, can take vessels 450 ft. long, 60 ft. beam, and drawing 20 ft. of water, and has been in most successful operation since 1883.[†]

Mr. Powell says:[‡]

> "The first floating dock is believed to have been constructed about the time of Peter the Great; a North Country captain having floated his ship into an old hulk, pumped the water out and made his repairs. The name of the hulk was 'Camel,' and this name the English still give to the pontoons that are used for raising ships."

The United States has been especially slow in the construction of large floating dry docks, probably because of the moderate cost at which wooden graving docks have been built. In general, such a dock, of much greater capacity, can be built at practically the same cost as a steel floating dock. On the other hand, the relative number of floating docks in the United States is very large, because their first cost is relatively less. As far as the speaker knows, Table 2 is a list of all the floating docks in the world, at the present time, of more than 10 000 tons capacity.

TABLE 2.—THE LARGE DOCKS OF THE WORLD.

Location.	Capacity.	Date of construction.
Portland	10 000	....
Hamburg	11 500	....
Antwerp	11 000	....
Baltimore	12 000	....
Hamburg	17 000	1897
Stettin	11 000	1898
Hoboken	10 000	1900
Port Mahon	13 000	1901
New York	12 000	1901
New Orleans	18 000	1901
Bermuda	17 500	1902
Pala	15 000	1903
Hamburg	18 000	1903
Rotterdam	15 600	1904

---

[*] "Notes on Dry Docks of the Great Lakes," by A. V. Powell, M. Am. Soc. C. E. *Journal* of the Western Society of Engineers, January, 1896, Vol. I, p. 1.

[†] A description of this lift may be found in *The Scientific American* of August 1st, 1896.

[‡] Powell, "Notes on Dry Docks of the Great Lakes."

Mr. Goodrich. Of those in the United States, none is noteworthy, except that at New Orleans. The specifications for it included the following items:

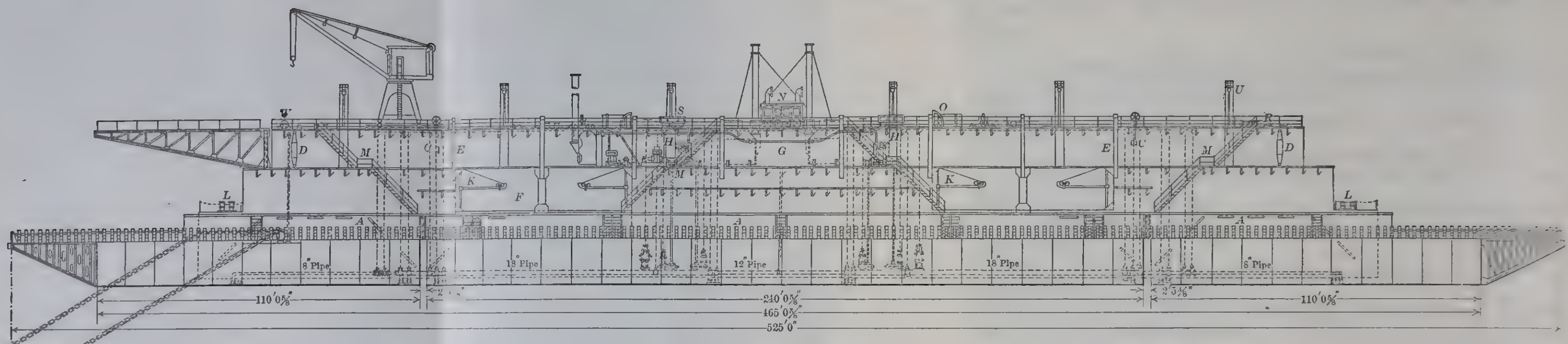
> "To be capable of lifting a vessel of 15 000 tons displacement, 450 ft. long, 27 ft. draft, and having two-thirds of her weight concentrated in the middle half of her weight.
>
> "Length over all, 525 ft., draft of water over keel-blocks, 28 ft., width, in clear, not less than 100 ft.
>
> "The dock must be so designed that vessels, when lifted upon it, shall be free from longitudinal strain, and also free from transverse strains and twisting.
>
> "The dock proper shall have transverse strength and stiffness sufficient for docking a battleship of 15 000 tons, with her entire weight carried on the keel-blocks.
>
> "The greatest longitudinal deflection allowable will be 1 in 3 000, with the most unfavorable load.
>
> "The greatest transverse deflection allowable will be 1 in 1 800, with the most unfavorable load.
>
> "The dock shall not careen more than 3° under the most unfavorable condition of loading, providing for the vessel landing 2 ft. off the longitudinal center line, and subject to wind pressure of 30 lb. per sq. ft.
>
> "The dock must be designed to lift a ship of 15 000 tons displacement above the level of the river, and with a freeboard of not less than 2 ft.
>
> "It may be in sections, and so designed as to be self-docking.
>
> "Designs for sectioned docks must make adequate provision for connecting the sections so that the dock may act as a unit, and the sections be kept level and in line without straining the ship; and so that, in case one of the sections shall lose its buoyancy, the connections of the sections shall be capable of distributing over the remaining sections the weight of the injured section and all the parts of the ship over the latter.
>
> "The entire structure must be of steel, except the keel-blocks, bilge-blocks, and shores.
>
> "All material must be of domestic manufacture."

The dock was built by the Maryland Steel Company, after a modified design of Lyonel Clark, M. I. N. S., and passed a satisfactory test before a Board of Naval Officers of which the speaker was a member. The Bermuda dock, referred to by Mr. Brereton, was built abroad, and this was the first one of steel to be built in the United States.

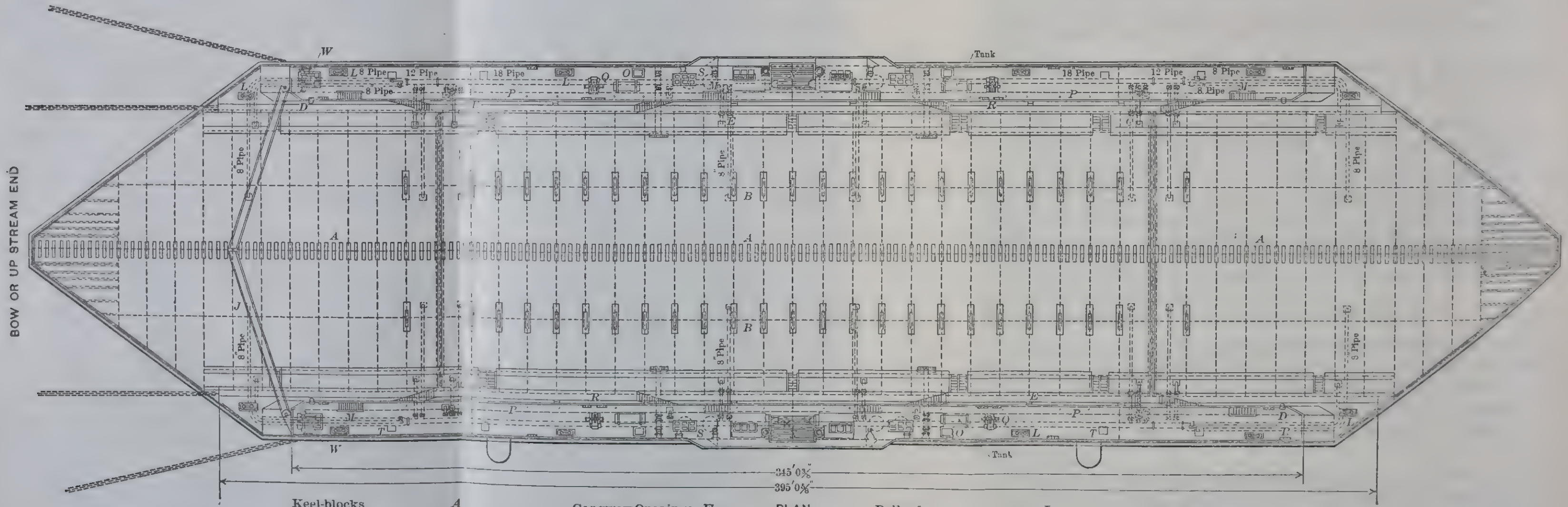
The general dimensions and arrangements of the dock are shown on Plate XLI and Fig. 5, and a view of the battleship, *Illinois,* in dock during the official test is shown on Plate XLII. The pumps are dimensioned so that almost exactly 1 hour was consumed in lifting the ship, from the time the centering shores were in place until the keel-blocks were bare; and the flooding valves were proportioned so odrich.

PLATE XLI. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
GOODRICH ON
DRY DOCKS.

FLOATING DRY DOCK FOR VESSELS OF 15 000 TONS, ALGIERS, LA.



SECTIONAL SIDE ELEVATION



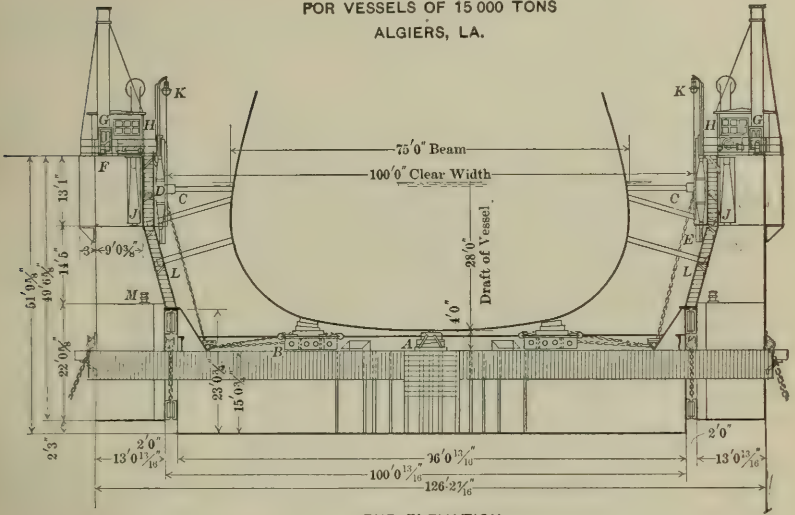
PLAN

Keel-blocks	A
Sliding Bilge-blocks	B
Mechanical Side-shores	C
Roller Fenders	D
Spring Timbers	E
Gangway Openings	F
Boiler-room	G
Engine-room	H
Flying Gangway	J
Hand-cranes	K
Bollards	L
Accommodation Ladders	M
Valve-house	N
Companions	O
Belaying Cleats	P
Winches	Q
Fairleads	R
Skylights	S
Hatches	T
Electric Arc Lamps	U
Windlass for Moving Gear	W

Mr. Goodrich. that it took just 1½ hours to sink the dock so as to float the battleship.

The dock proved amply stiff for the uses for which it was designed, though not quite up to the specifications, but it was exceedingly sensitive to temperature differences in different parts, and to changes of temperature in air and water. It was a practical impossibility to get the keel-blocks to one grade and to have the docking keel-blocks at the same grade as the center ones, within a small fraction of an inch. In docking the *Illinois,* no shores were used, except for purposes of centering the vessel in the dock, the docking keels serving to maintain the ship in a vertical position.

FLOATING DRY DOCK.
FOR VESSELS OF 15 000 TONS
ALGIERS, LA.



END ELEVATION

Keel-blocks	A	Spring Timbers	E	Flying Gangway	J
Sliding Bilge-blocks	B	Winches	F	Electric Arc Lamps	K
Mechanical Side-shores	C	Companions	G	Accomodation Ladders	L
Roller Fenders	D	Valve-house	H	Bollards	M

FIG. 5.

Some difficulty was found in carrying out the self-docking operations, due to structural design. These and various other minor deficiencies have been largely overcome in a dock, now under construction by the same company, for the Government, for the Philippine Naval Station.*

---

* A full discussion of this dock may be found in a paper by A. C. Cunningham, U. S. N., entitled "The Cavite Steel Floating Dry Dock," *Journal*, Am. Soc. Naval Engrs., Vol. XV, No. 2.

Mr. Goodrich. Some special items in which the specification for this dock differed from that for the New Orleans dock are the following:

"The dock shall not be less than 500 ft. long, over all, none of which length shall consist of bracketed platforms without lifting power.

"The dock shall have a clear width between fenders of not less than 100 ft.

"The decks of side walls shall have not less than 8 ft. of clear height above the water, with 30 ft. draft over 4-ft. keel-blocks.

"The dock shall have a lifting capacity of not less than 16 000 gross tons, uniformly distributed over the entire length, with the main deck not less than 2 ft. above the water, and with not less than 1 ft. of water in the compartments.

"No portion of the dock or its connections shall have a stress of more than 10 000 lb. per sq. in. under the specified loads, or 15 000 lb. per sq. in. in self-docking, with a wind pressure of 30 lb. per sq. ft. of exposed surface.

"The dock shall be designed to dock all classes of vessels of the United States Navy, either centrally or with the center line of the keel 1 ft. off the center line of the dock, with a freeboard of 2 ft., and shall provide for bearing over the full length of the dock.

"The dock shall be so designed that the entire weight of a battleship may be safely carried by the main keel-blocks, or one-half the weight on each line of docking keel-blocks, in whichever position the ship may be docked. The side walls shall be designed to take shoring at any point that may be necessary.

"The working deck of the dock shall be flush-plated and so strengthened that docking keel-blocks may be placed in any position.

"With any specified ship load docked centrally and all compartments pumped uniformly until the dock has a freeboard of 2 ft., the longitudinal and lateral deflections over the entire working deck of the dock shall not exceed 1 in 2 000.

"Telephone or speaking tube communication shall be provided from one side wall of the dock to the other, along the side walls, and to the engine-rooms.

"Provision shall be made for a central headline and for hauling the same from side walls.

"The dock shall be fitted with a reliable pneumatic or hydraulic indicator system to show the depth of water in all compartments at all times.

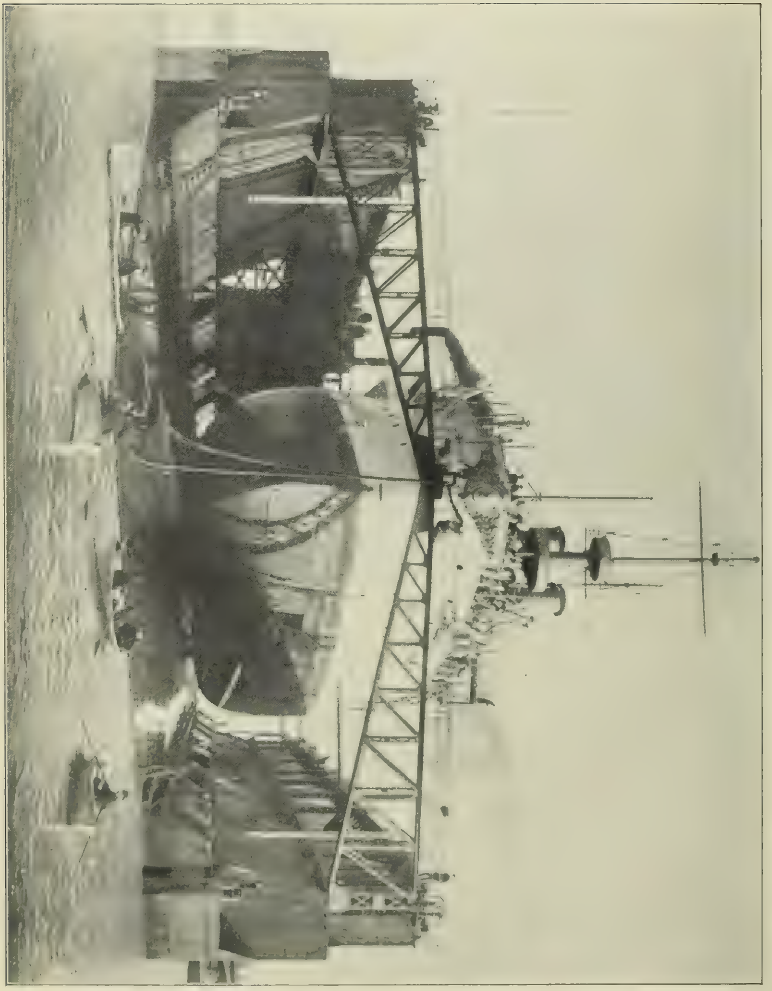
"When self-docking, all under-water portions shall be raised to a clear height of not less than 5 ft., and shall be safely and readily accessible for inspection, painting and repairs.

"With the dock at light draft line, all self-docking and strain-transmission connections shall be above water.

"The dock shall be designed to lift a load of 16 000 gross tons, with a draft of 30 ft., clear of the water in 4 hours. Lighter loads of less draft shall be lifted in a correspondingly shorter time, and the pumps shall readily operate under a head of 35 ft.

"Observations shall be made for deflections and permanent set during the dockings, by specially designed instruments, furnished by the contractor, which will become part of the dock outfit. In

PLATE XLII. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
GOODRICH ON
DRY DOCKS.



THE BATTLESHIP *Illinois* IN DOCK.

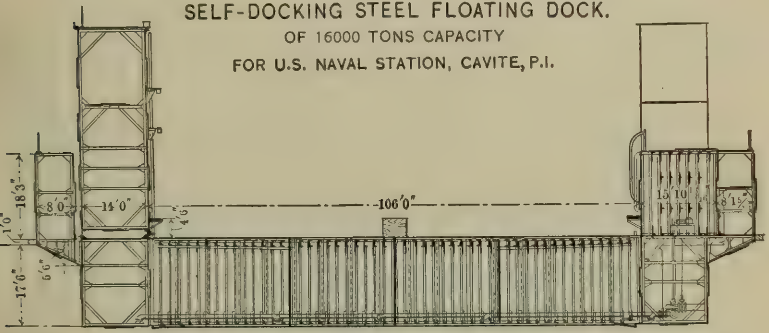
Mr. Goodrich.

determining the final deflection, allowance shall be made for permanent set and temperature deflections, and the blocking shall be straight."

This specification provides a dock which will take with ease any of the present naval vessels of the United States, and will also safely dock a battleship of 20 000 tons displacement, or an armored cruiser 600 ft. in length. The present maxima are approximately 16 000 tons, and 500 ft., respectively.

It is understood that already the Navy Department is preparing designs for a class of battleships which will approach very closely to 20 000 tons displacement.

The general forms and dimensions of this dock are shown on Plate XLIII and Fig. 6, here reproduced through the courtesy of the Maryland Steel Company.


SELF-DOCKING STEEL FLOATING DOCK.
OF 16000 TONS CAPACITY
FOR U.S. NAVAL STATION, CAVITE, P.I.

Cross-section through end pontoon, showing supplementary side walls, chamber at end for location of operating machinery, and connection at left between main side wall and end section.

Fig. 6.

The largest of the commercial floating dry docks in the United States is the wooden sectional floating dock of the Morse Iron Works at their plant in Brooklyn. Fig. 7 shows its general design. This dock is peculiar in that it uses electric power for pumping purposes. It was one of the first in the country to do so. Another peculiarity is the method of bracing the hull.

In a wooden structure such as this, there is great difficulty in maintaining an exactly equal lifting power upon each section, and the dock is apt to fail to act as a unit, because of lack of rigid connection between the sections. In steel structures this is usually made rigid with bolts, but in wooden structures it is generally accomplished by using heavy timbers working in sleeves upon two adjoining sections. In case of unequal leakage of sections there is apt to be a considerable strain thrown upon the hull of the vessel,

Mr. Goodrich. so that special attention has to be given to this point. Great care has also to be taken, in docking a vessel, to have perfectly uniform lifting power exercised by each section.

If the keel-blocks of such sectional docks could be constructed in the form of hydraulic jacks with communicating pipes, so that exact lifting powers could be maintained on all blocks, a great advantage would be secured. This condition of affairs actually exists in hydraulic lifts, where care has been taken to connect the power main in a proper manner. No particular reason is evident why this arrangement could not be carried out in sectional docks. Of course, with commercial vessels, there is not the necessity for such care as must be exercised in the docking of naval vessels. In the latter, the load curve is always irregular (due to turrets, armament, and other causes), and the armor plating produces strains in the hull which are never encountered in commercial vessels. For the latter reason, many naval vessels are provided with special docking keels, while these are entirely omitted in all commercial vessels. Correspondingly, docks must be designed and constructed in view of these facts, so that a naval dry dock must have greater stability of floor, and greater lateral stiffness, than required in commercial docks. In any case, the dock and the vessel seem to supplement variations in longitudinal stiffness in each other, and come together so as to distribute strains pretty well.

END VIEW OF ONE OF THE 80-FOOT PONTOONS OF THE MORSE DRY DOCK.

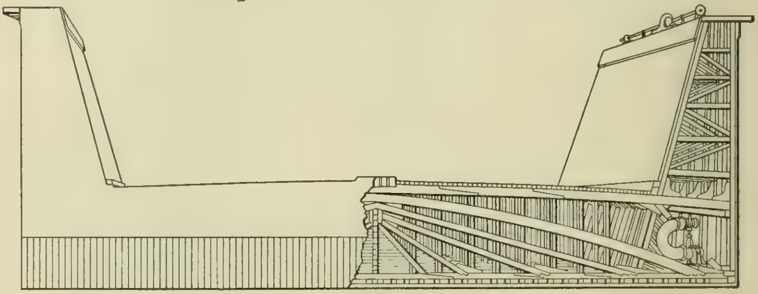


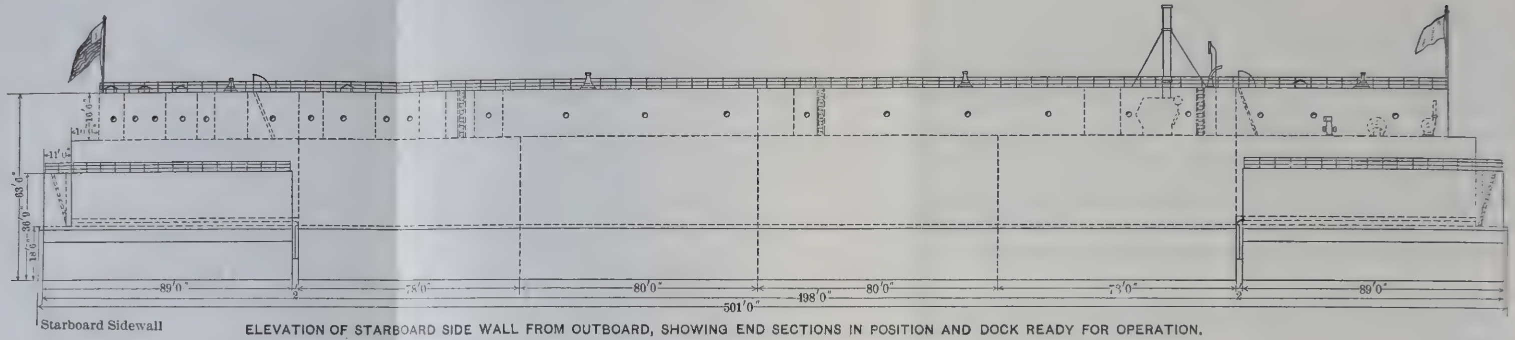
Fig. 7.

Municipal and governmental ownership is not as advanced in the United States as in some countries. In the United States few dry docks are thus owned and operated. Table 3 is a list of the graving docks at the various navy yards controlled by the Navy Department.

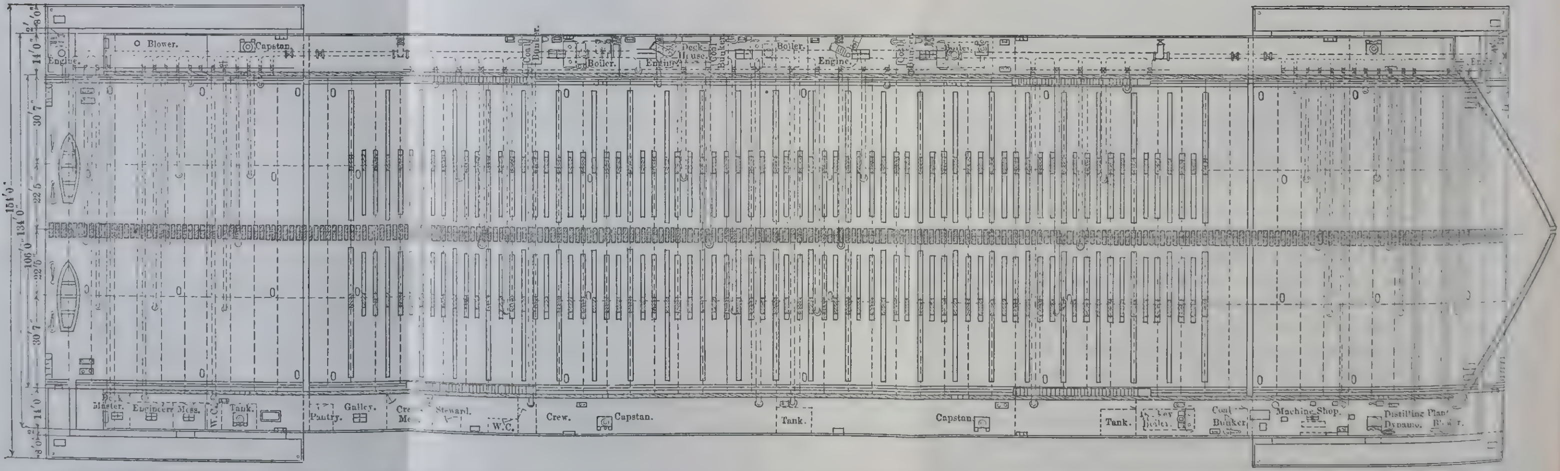
The only example of municipal ownership, within the speaker's

ich.

SELF-DOCKING STEEL FLOATING DRYDOCK FOR U.S. NAVAL STATION, CAVITE, PHILIPPINE ISLANDS.



ELEVATION OF STARBOARD SIDE WALL FROM OUTBOARD, SHOWING END SECTIONS IN POSITION AND DOCK READY FOR OPERATION.



PLAN SHOWING LOCATION OF PUMPING MACHINERY IN PORT SIDE WALL, DISTRIBUTION OF WATERTIGHT BULKHEADS AND PIPING, AND END SECTIONS IN POSITION, WITH DOCK READY FOR OPERATION.

Mr. Goodrich.

knowledge, is the floating dry dock owned by the Harbor Commissioners of the Port of Portland, Oregon. It has the following dimensions:

Length	468 ft. 0 in.
Width, between wings.................	82 “ 0 “
Depth of water, over blocks............	25 “ 0 “

One of the reasons why the United States has so few large dry docks is probably because only one or two municipalities actually have in their hands the care and construction of the water-front property. New York City is an example of such a municipality, but, strange to say, it has no dock owned by the City. The matter has been suggested on several occasions, but nothing has been done, further than the preparation of estimates.

TABLE 3.—GRAVING DOCKS OWNED BY THE UNITED STATES NAVY DEPARTMENT.

Locality.	Material.	Length over all.	Width of entrance (top).	Depth of water over sill.	Remarks.
Boston, Mass...........	Granite.	396 ft. 6 in.	61 ft. 1 in.	25 ft. 5 in.	
“ “	Granite and Concrete.	750 “ 0 “	21 “ 9 “	30 “ 0 “	Under construction.
League Island, Pa......	Wood and Concrete.	500 “ 0 “	89 “ 11 “	25 “ 5 “	
“ “	Granite and Concrete.	750 “ 0 “	102 “ 7 “	30 “ 0 “	
Mare Island, Cal.......	Granite.	518 “	80 “ 7 “	27 “ 5 “	Under construction.
“ “ “	Granite and Concrete.	....	....	....	Under construction.
New York, N. Y........	Granite.	369 ft. 3 in.	66 ft. 4 in.	25 ft. 1 in.	
“ “ “	Concrete.	470 “ 7 “	90 “ 1 “	26 “ 0 “	
“ “ “	Wood.	668 “ 7 “	105 “ 0 “	29 “ 5 “	
Norfolk, Va............	Granite.	332 “ 5 “	60 “ 0 “	25 “ 1 “	
“ “	Wood.	500 “ 0 “	85 “ 0 “	25 “ 6 “	
Port Royal, S. C........	Wood.	495 “ 0 “	97 “ 6 “	26 “ 0 “	
Portsmouth, N. H......	Granite and Concrete.	750 “ 0 “	101 “ 9 “	30 “ 0 “	Under construction.
Puget Sound, Wash....	Wood and Masonry.	650 “ 5 “	92 “ 9 “	30 “ 0 “	

The Navy Department possesses but three floating docks, as follows:

Algiers, La.............	Steel.	525 ft. 0 in.	100 ft. 0 in.	28 ft. 0 in.	
Pensacola, Fla.........	Wood.	234 “ 8 “	67 “ 6 “	17 “ 0 “	
Portsmouth, N. H......	Wood.	350 “ 0 “	90 “ 8 “	21 “ 6 “	

Mr. Goodrich. It has been entirely within the last decade that any great advance has been made in the construction of large floating dry docks in the United States. During that period, the largest wooden dock (above described), and the only steel dock thus far put into operation in the United States have been built. However, it is felt that at the present time the advancement in design and construction is fully abreast of the practice abroad. The naval dock now under construction is to be in accordance with a specification which "is the most comprehensive and complete of any that has yet been issued for a floating dock."*

In comparison with the floating dock designed by Mr. Lyonel Clark for the Austrian Government, for its Naval Station at Pala, which may be considered as representative of the latest and best practice abroad, it is believed that the Cavite Dock is a step in advance. Of the former dock, Mr. Cunningham remarks:

> "It is a bolted sectional design. The bolts are carried around through a special chamber and below the water line of the dock, and it is believed that it will be difficult to keep them dry, and inconvenient to make and unmake the connection in self-docking operations on account of the flooding of the chamber."

It is only fair to Mr. Clark to add, however, that in the design which he submitted for the Cavite Dock, he brought the submerged joints above the water line, and in other ways produced the best design he has yet developed.

In the Cavite Dock, it is to be noted that all joints connecting the end portions with the side walls are horizontal, and that the side walls are built to the full depth of, and continuous with, the center portion, providing an exceedingly rigid construction.

In the short historical note in his article, "Notes on Dry Docks of the Great Lakes,"† Mr. Powell says:

> "The dry dock, as we now know it, seems to have been developed from the 'grave'; in England to-day it is known as a graving dock. Where the tides were available, the vessels were beached at high tide, repaired while the tide was out, and floated at the next tide. This method was followed by the excavation of a bed in which to place the ship to be repaired, called a 'grave.' After the vessel was in place and the tide ran out, the 'grave' was closed at the outer end by an embankment thrown across it; this allowed continuous work on repairs. This method is still in use. The 'Petrel' of the United States navy was docked at New Chwang, Manchooria, China, in this way during the winter of 1894-5. * * * The Chinese used the method four hundred years ago."

Both Mr. Powell and Mr. Brereton speak of the beaching of the *Great Eastern*, and it may be added that another United States naval vessel, the *Helena*, spent several months at New Chwang in dock

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* Cunningham, in *Journal*, Am. Soc. Naval Engrs., Vol. XV, No. 2.

† *Journal* of the Western Society of Engineers, January, 1896, Vol. I, p. 1.

Mr. Goodrich.

during the winter of 1903-04. We have repeatedly read of the repairs to Russian war vessels in the mud dock at Port Arthur, and Lloyd's Register mentions similar docks at Taku, and several at Calcutta, in which stakes are used to close the entrances. Mr. Timonoff's idea thus seems entirely feasible, and to have been tried successfully in past time. It would seem possible to devise some means to make use of the ships' bilge pumps in removing the water from the enclosure, described by Mr. Timonoff, thus obviating the necessity, which would usually be an impossibility also, of securing a special pumping plant.

The principal dimensions of most of the large dry docks in the world are given in Table 4. Only those more than 700 ft. long, or with entrances more than 90 ft. wide, or with a depth of more than 40 ft. over keel-blocks, are included.

In Table 4 where two figures are given for any of the dimensions of a dock, the upper one is for the top dimension and the bottom one for the dimension on the keel-blocks or the floor. In many cases where a single dimension only is given, it is not known to exactly what part of the dock it applies. However, the top dimension may usually be understood.

While not relatively as numerous as abroad, the dry docks in the United States are fairly so, and several are of some interest. There is on the St. Croix River between Calais and Passamaquoddy Bay, a natural dry dock.* At that point a brook has cut a channel through the river bank down to the level of low tide, the difference in tide levels at this place being nearly 25 ft. Several hundred feet back from the river, a 10-ft. wall of stone laid in cement was built. Sills were laid in a properly arranged opening left in the wall, and a pair of ordinary lock-gates were put in place, opening outward. A pipe, controlled by a valve, was laid in the wall, to carry off water intercepted by the wall; and a by-pass cut, above the level of high tide, provided an outlet for the brook water during floodings of the dock. A few well-bedded cross-timbers, for supporting the keel of the vessel, completes this serviceable dry dock. The high range of tide provides all the appliances needed to fill and empty the dock. It has been in successful operation for some years.

In North America, according to Lloyd's, there are 57 dry docks of the excavated type; 5 others, omitted in that list, must be added.

In length they range as follows:

Length.	Number.	Length.	Number.
100 to 199 ft.	6	500 to 599 ft.	9
200 to 299 "	10	600 to 699 "	5
300 to 399 "	12	700 to 799 "	0
400 to 499 "	19	800 to 899 "	1

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* *Engineering News*, Sept. 8th, 1898.

Mr. Goodrich.

TABLE 4.—Large Dry Docks of the World.

Location.	Length.	Width.	Depth.
Bahia Blanca	713 ft.	84 ft.	33 ft.
Bremerton	651 "	91 "	30 "
	574 "	....	....
Bangkok	300 "	90 "	13 "
	275 "	....	....
Barry, No. 1	784 "	60 "	25 "
Barry, Commercial	868 "	60 "	27 "
Belfast	825 "	80 "	26 "
	800 "	....	....
Birkenhead, No. 1	930 "	60 "	24 "
Birkenhead, No. 2	750 "	48 "	27 "
Birkenhead, No. 3	750 "	85 "	27 "
Bremerhaven	755 "	98 "	35 "
	742 "	....	....
Brest	738 "	....	....
	....	82 "	....
Brest, No. 7	398 "	112 "	32 "
	375 "	....	....
Brest, No. 8	348 "	112 "	33 "
	335 "	....	....
Carthagena	492 "	99 "	32 "
	430 "	49 "	....
Ceylon	720 "	85 "	32 "
	700 "	....	....
Chatham	478 "	95 "	36 "
	....	....	34 "
Devonport	417 "	94 "	35 "
Ferrol, San Julian	476 "	79 "	48 "
	410 "	....	....
Gibraltar, No. 2	563 "	95 "	39 "
	550 "	....	....
Gibraltar, No. 3	463 "	95 "	39 "
	450 "	....	....
Gibraltar, No. 1	863 "	95 "	39 "
	850 "	....	....
Genoa	702 "	60 "	28 "
	695 "	....	....
Glasgow	880 "	83 "	27 "
Haulbowline	426 "	94 "	33 "
Havre	656 "	98 "	29 "
	625 "	....	....
Hongkong	700 "	....	....
Keyham, No. 8	480 "	95 "	36 "
Keyham, No. 9	745 "	95 "	36 "
Keyham, No. 10	741 "	95 "	48 "
Kure	....	93 "	36 "
	486 "	....	....
Liverpool, Canada Dock	926 "	94 "	32 "
Liverpool, No. 1 West	759 "	60 "	23 "
Liverpool, No. 2 Middle	930 "	60 "	23 "
Liverpool, No. 3 East	768 "	60 "	23 "
London, No. 1, Tilbury	846 "	70 "	35 "
London, No 2, Tilbury	846 "	60 "	30 "
Mare Island	755 "	101 "	30 "
	728 "	....	....
Newport, Tredegar	708 "	65 "	29 "
Newport News, Timber	639 "	96 "	25 "
	593 "	50 "	....
Newport News	861 "	103 "	30 "
	804 "	80 "	....
New York, No. 3	669 "	105 "	30 "
	625 "	70 "	....
New York, No. 2	471 "	90 "	26 "
	451 "	72 "	....
New York, Erie Basin	501 "	100 "	20 "
	485 "	....	....
Philadelphia	739 "	104 "	30 "
	707 "	....	....
Portsmouth, U. S.	750 "	100 "	30 "
	725 "	....	....

TABLE 4.—(*Continued.*)

Location.	Length.	Width.	Depth.
Portsmouth, Deep Lock	461 ft.	82 ft.	42 ft.
Portsmouth, North Lock	467 "	82 ,,	43 "
	....	....	34 "
Portsmouth, South Lock	467 "	82 "	42 "
	....	80 "	33 "
Portsmouth, No. 15	564 "	94 "	34 "
San Francisco	750 "	104 "	30 "
	714 "	86 "	....
Singapore	800 "	95 "	32 "
Southampton, No. 5	750 "	91 "	33 "
	705 "	....	....
Southampton, No. 6	860 "	90 "	33 "
	845 "	....	....
Spezia, No. 5	702 "	106 "	33 "
	687 "	81 "	....
Spezia, No. 6	505 "	90 "	33 "
	491 "	71 "	....
Sidney	765 "	83 "	28 "
Paranto	708 "	108 "	32 "
	690 "	95 "	33 "
Toulon	440 "	95 "	33 "
	424 "	....	....
Valetta, No. 2	750 "	....	....
Valetta, Hamilton	558 "	94 "	36 "
Vladivostock	572 "	90 "	30 "
	512 "	....	....
Wilmington	350 "	90 "	14 "
	330 "	....	....
Yokohoma	531 "	94 "	28 "
	484 "	....	....

The width of entrance will be seen, from Fig. 8, to vary considerably, but in general it is less with the short docks, and seems to approach 80 ft. as an average width for all docks over 500 ft. in length. In general, naval docks have wider entrances than commercial ones, because of the relatively greater ratio of width to length of naval vessels. In such docks the practice seems to be tending to a width of entrance of 100 ft., with the entrance abutments built with just enough batter to free readily the ship-shaped caissons universally used. The depth of water on the sill of various docks depends largely upon the locality. On the Lakes the depth rarely reaches 20 ft., while the seaboard of each coast has several docks with depths of nearly 30 ft. The shape of the cross-section in the United States varies most with the materials of construction. When the structure is of wood, the slope of the sides is made as nearly as possible that of the natural slope of the earth in which the dock is built. This gives a wide top and relatively slight side slopes, and the timbers used make a large number of small steps or altars. With masonry or concrete, the shape is made to conform more nearly to that of the vessels, and the altars are made fewer and higher. In general, more altars are to be found in docks in the United States than in those abroad.

Fig. 9 is a cross-section of Dry Dock No. 2, New York Navy

Mr. Goodrich. Yard, as it was originally constructed in wood, and as it was reconstructed in concrete. The line of the altars in each case is straight. In some docks this line is made somewhat concave, so as to conform very closely to the vessels to be docked. Fig. 10 is a cross-section of the dock of the Chicago Shipbuilding Company. The speaker does not know of any dock in the United States in which the altar line is convex, as is the case in Dock No. 3 at Glasgow, Fig. 11.

When the dock conforms very closely to the size and shape of the ship to be docked, care has to be taken in pumping, so as not to land the ship on the blocks prematurely, or to pump the water down so fast that proper shores cannot be placed as rapidly as needed. Of course, with no ship in dock, the smaller the dock and the larger the capacity of the pumps, the more economical is the process.

LENGTHS AND WIDTHS OF ENTRANCES OF DRY DOCKS OF THE UNITED STATES.

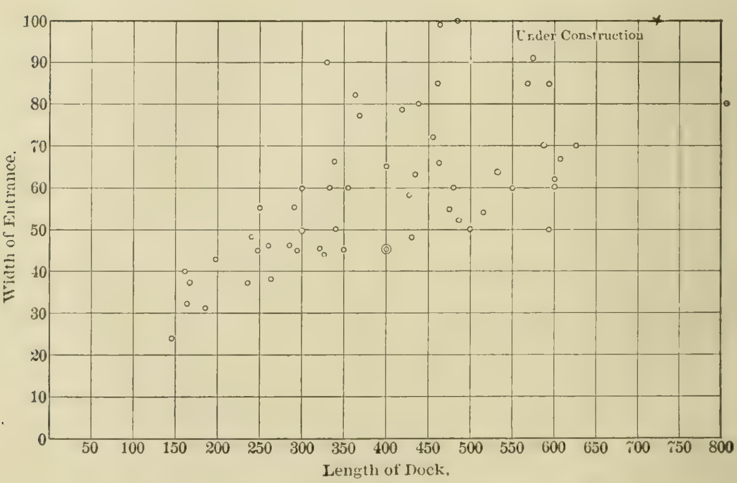

FIG. 8.

With docks approximating the shape of vessels, little light penetrates beneath their bottoms when in dock, and there is no ventilation there. With the wide flat bottoms of modern vessels, however, these faults become impossible of avoidance, making artificial light and sometimes artificial ventilation necessary, so that such an objection to the shape of the dock fails.

Ten years ago wooden docks were in great vogue. The Navy was building them exclusively, and their relatively less first cost (which is the item which most largely influences most American pioneer commercial enterprises) gave them an almost exclusive place with private companies.

Mr. Goodrich.

The first successful wooden dry dock in the United States[*] was formed from the hulk of an old "merchantman," in Maine. About 1854 Mr. James E. Simpson constructed a timber-box dry dock in Boston for which he took out a patent. A sectional drawing of this dock shows that substantial clay-filled coffer-dams formed the main walls. The floor was puddled underneath with clay, and constructed of heavy timbers reinforced with large braces. Heavy braces also supported the altars, and other braces sloped from the floor to the sides, stiffening the entire structure.

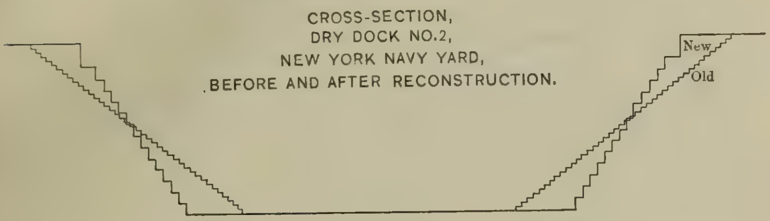

FIG. 9.

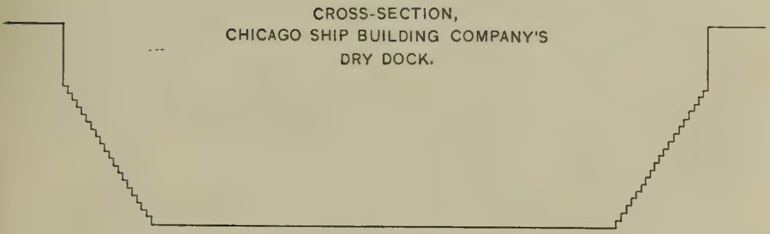

FIG. 10.

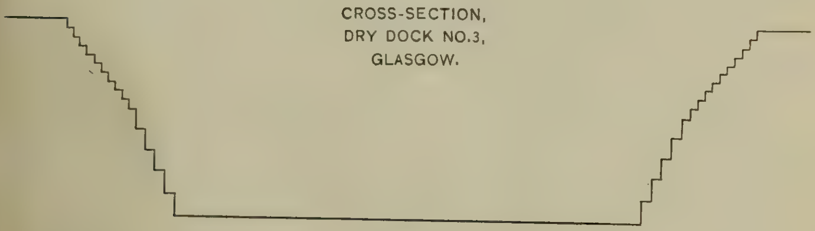

FIG. 11.

In 1878 other patents were taken out by Mr. Simpson, covering special details and many improvements, and again in 1886 another patent was issued for such structures. Mr. Simpson's company had

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[*] Robert A. Cummings, in *Engineering News*, Sept. 2d, 1877.

Mr. Goodrich. for so long a time a practical monopoly of dry dock building that a great many of their docks are even to-day called "Simpson Docks." The 1886 patent covered "a concrete bed carried up to the tops of the longitudinal and cross-timbers" of the dock floor. In 1890 Ralph G. Packard, M. Am. Soc. C. E., received a patent covering improvements in such docks. The principal improvements were, a combination, with the usual parts, of a row of sheet-piling on each side, extending up to the inclined braces, about one-tenth of their length up from their lower ends; and of concrete around the heads of the floor foundation piles and timbers, sloped so as "to form longitudinal water-ways in the spaces between all the longitudinal timbers in the bottom of the dock for clearing the space below the flooring from foreign substances by flushing the same longitudinally."

In 1891, M. T. Endicott, M. Am. Soc. C. E., now Rear Admiral, U. S. N., Chief of the Bureau of Yards and Docks of the Navy Department, took out a patent with the following special features:

> "Inclined piles driven at an angle from the vertical, and forming a part of the side structure of the dock. * * * The bottom or floor constructed partly of wood and partly of concrete with a system of tranverse and longitudinal drains underneath the concrete, conducting the sub-drainage water to the well without its passing up through the bottom or floor."

The object in driving the piles on an incline was to bring them more clearly in the line of the strains upon them either from the thrust of shores from the ship, or from the hydrostatic pressure of water, in front or rear, when the dock was full or empty. While sub-surface drains had previously been used in masonry docks, the above claim shows that their use, now so common in wooden docks, dates from that time.

From time to time since 1891, other patents have been issued, covering various features in the construction of wooden docks, but the tendency in these has clearly been toward the use of greater quantities of concrete in combination with wood, until the use of any wood at all became almost obviously unnecessary.

No wooden dry docks exist which are especially noteworthy. The largest one belonging to the Navy is Dry Dock No. 3, New York Navy Yard. It has the following dimensions:

Length over all	670.0 ft.
" on bottom	626.7 "
Breadth of entrance, top	105.0 "
" " " bottom	70.3 "
Depth of water on sill	28.0 "

The largest wooden dry dock in the United States, and probably in the world, belongs to the Newport News Ship Building and Dry

Dock Company, was completed in 1900, and is of the following dimensions: Mr. Goodrich.

Length over all....................	860 ft.	6 in.
" on bottom.................	804 "	0 "
Breadth of entrance, top............	102 "	10 "
" " " bottom	80 "	0 "
Depth of water on sill..............	30 "	0 "
Pumps	Horizontal-Centrifugal	
Power	Electric.	

The Chicago Ship-Building Company has a dry dock which was converted to its present use from a slip, and in cross-section it is very similar to the first one built by Simpson. It has also been used for the launching (broadside) of vessels. The sides are held by sheet-piling properly tied back, and the entrance is reinforced by a crib on each side. Gates are used in many smaller wooden docks, but the ship-shaped caisson is used in the majority of cases.

The best practice ten years ago may be seen by extracts from the specifications issued in 1892 for the Puget Sound Naval Dry Dock.

> "The dry dock will be built of timber and concrete from the abutments inward, and the remainder, forming the entrance work, of cement and stone masonry.
>
> "The engine, pump and boiler-house shall be one story, of brick with stone trimmings, and steel roof-trusses covered with a slate roof.
>
> "The culverts and pump-well shall be of good hard-burned brick.
>
> "The pumps are to be of the centrifugal type, balanced, and driven by vertical, high-pressure, non-compound engines.
>
> "The caisson, a floating gate, is to be of boat form."

At the present time the tendency in the United States is entirely toward docks of masonry or concrete, and even of reinforced concrete. This reversion took place about 1898-1900, and is clearly set forth by the discussions before engineering societies, in the engineering magazines, etc. In March, 1899, there was an informal discussion before the American Society of Civil Engineers on "Dry Docks—Stone *vs.* Wood,"* and a glance at it and at the technical periodicals of that date gives the various arguments advanced by each side. An extract from the annual report of the Chief of the Bureau of Yards and Docks of the Navy for 1899 will give the best view of the situation. It also includes a brief historical sketch of the docks of the Navy.

> "When the Government contemplated entering upon the construction of dry docks for the Navy, in the early part of this century, Congress provided that the Secretary of the Navy should call in to

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* *Transactions*, Am. Soc. C. E., Vol. XLI, p. 554.

. Goodrich. his aid some skillful engineer to locate and design the dry docks to be authorized.

* * * * * * * * *

"Under the authority conferred, the Department called in an eminent civil engineer, Col. Loammi Baldwin, of Boston, Mass., first as designer and then as constructing engineer, and the result was the construction of two masonry graving docks, one at Boston and one at Norfolk, which are classed with the finest examples of work of their kind in this or any other country. These two docks are in service in the Navy to-day, after a period of sixty-five years, in good, substantial condition, with almost an insignificant cost for repairs upon the dry-dock structure proper since their completion in consideration of the long time they have been in service.

"These were followed by masonry dry docks at Brooklyn and Mare Island, the latter being largely of concrete, which at the time of its construction had come very largely into use in engineering structures, supplanting cut-stone masonry to a great extent.

"Subsequently, when it became necessary to increase the docking facilities of the Navy, the Government entered upon the construction of floating dry docks, and several of these were built of both the balance and sectional type, the material of construction being timber. These served their purpose for a number of years, but they deteriorated rapidly and ere long they reached the stage when their continuance in service meant rebuilding, amounting almost to new construction. They were also found to be not so satisfactory as the masonry graving docks, and they were allowed to pass out of existence until there is only one left, the small balance dock at the Portsmouth, N. H., Navy Yard, which is now safe for vessels up to about 1 000 tons displacement.*

"As these dry docks went out of service and the vessels of the Navy were increasing in number, it became necessary to provide other docks. At this juncture the timber dry dock was pressed upon the attention of Congress by those interested in its construction and a few naval officers who advocated that type. In the year 1887 Congress was launched upon a third policy in the matter of its dry docks, being the construction of graving docks of timber. These have followed, one after another, until at the present time there are six timber graving docks completed and in use at the navy-yards, more than half of the docks of all types in the naval establishment.

* * * * * * * * *

"The first of these timber dry docks was completed in 1889, the last one in 1898, and while the service has extended over only a few years, the experience has been such as to demonstrate conclusively that timber graving dry docks of the capacity required by the Navy are really expensive temporary structures, unreliable, and unsafe.

* * * * * * * * *

"During this period there has been only one repair of any extent to the masonry (docks). The Brooklyn dry dock is the one referred to. This was completed in 1854. * * * When these repairs had

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* Its original capacity was 5 000 tons, and its use will probably be entirely discontinued as soon as the masonry dock now under construction is completed.

For the complete description of these structures see "Naval Dry Docks of the United States," by C. B. Stuart.

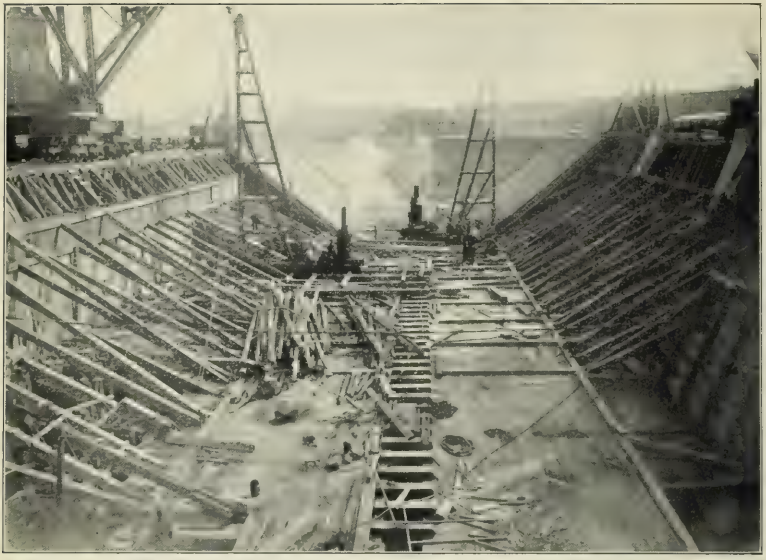

FIG. 1.—DRY DOCK NO. 2, NEW YORK NAVY YARD.

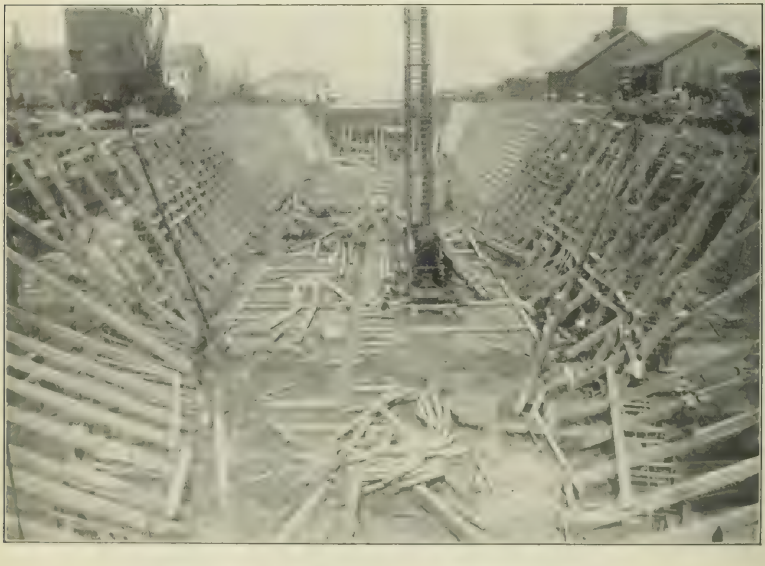

FIG. 2.—DRY DOCK NO. 2, NEW YORK NAVY YARD.

been completed,* at the end of the year 1887, the work was in fine condition and has so continued to this day. Mr. Goodrich.

"With this single exception no stone dry dock belonging to the United States Government has received any extended repairs except to those accessory structures which are common to all dry docks, whether of timber or masonry, and therefore do not enter into the comparison."

* * * * * * * * *

"Repairs to Dry Docks for Eight years, 1892-1899, upon Structures proper.†

" Location.	Completed.	Masonry.	Timber.	Total cost.
" Boston..................	1833	$2 620.69	....	$2 626.69
" New York..............	1851	1 765.80	....	1 765.80
" New York, No. 2........	1890	....	$302 342.14	302 342.14
" League Island..........	1891	....	70 721.38	70 721.38
" Norfolk.................	1834	156.97	....	156.97
" Norfolk, No. 2..........	1899	....	53 009.74	53 009.74
" Total..........		$4 543.46	$426 073.26	$430 616.72

"The accompanying table shows the repairs upon each one of the graving docks in service during the years following 1888, giving the total repairs upon each dock proper for each year, as well as those upon the accessories, so that comparative results may be seen, both in the matter of total repairs of all kinds and of those upon the dry dock structure proper. * * * The table * * * shows that the repairs to the masonry structures have been practically nothing during a period in which repairs to the timber dry docks have been extraordinarily large at the most favorable period of their lives. * * * It will be seen that in the case of at least one of these timber dry docks, scarcely ten years old, the repairs will have amounted to 50 per cent. of the original cost.

"Some of these repairs just referred to have been of an unusual character in that they have been upon a line somewhat different from the original construction; for instance, at the Norfolk dry dock the repairs have included the renewal of the upper portion of the altar system in concrete instead of timber. This is also true of the repairs in the cases of the League Island dry dock and dry dock No. 2 at the New York Navy-Yard, which are now being made. In the former case the upper altars are being renewed in concrete, and in the latter the entire entrance and a portion of the side structure of the interior are being rebuilt in concrete. These circumstances render the repairs more expensive than they would have been had the restoration been in timber, as was the original construction. However, repairs of this character were deemed necessary in order to make the work substantial and safe, more durable in its character, the repairs less frequent, and less in cost eventually. They must be

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* At a cost of about $80 000.

† This comparison is between the three masonry dry docks upon the Atlantic Coast and the three timber dry docks similarly located which have been in use eight years.

Mr. Goodrich. regarded as repairs properly chargeable to a structure of the kind, and in the long run will make the showing of repairs more favorable than would be the case if they were made with the same class of material as the original construction.

"The experience the Navy has had with these docks has demonstrated, if such demonstration were necessary, that a timber dry dock is a temporary structure. Docks of this kind in private establishments, where the cost of repairs is being kept down to the lowest level, have not been very expensive in the early years of the dock's life, but at from 20 to 25 years of age they have required repairs so extensive in character as to amount to a practical rebuilding of the upper portion of the structure, and frequently in its entire reconstruction. * * *

"In a recent discussion of the subject of dry-dock construction* before a technical society, which has been published, an engineer of prominence† from Canada took part. As he had then made a careful inspection of most of the dry docks of this country, his views are of value. He stated that he had recently examined all the large dry docks on the Atlantic Coast from Halifax to Norfolk, and on the St. Lawrence and the Great Lakes from Levis to Lorain, mainly with respect to the choice of material for the construction of a dry dock of large size at Montreal. Some of his observations were as follows:

"'The wooden dry docks of both public and private ownership show general weakness of construction, and a rather rapid decay. * * * The wooden dry dock at Portland, Me., built in 1869, has had no recent repairs, and its altars and pile heads above low water are entirely rotten.

"'At Boston the altars and other lining of the three wooden docks built in 1854 to 1864 have been practically all rebuilt inside, and have required frequent repairs. The largest one is leaking beneath the entrance. The two private docks at Erie Basin, Brooklyn, built in 1866, were all relined in 1881, and concrete substituted for wood in the upper five altars. The wooden dock at Cramp's, Philadelphia, built in 1876, has largely failed. The altars and the slopes near the abutments have bulged in badly at places; the altars, from weakness and decay, have been stove in at places, revealing cavities behind, from which the earth slopes have been washed down. The League Island dock of the United States Navy, built in 1891, is notably weak, and has bulged in badly. While occupied by the United States cruiser *Columbia*, a month ago, the abutments were shored up to prevent collapse. There are serious leaks of water and mud in the bottom and lower altars of one side, and the earth slopes behind the altars have run down in several places, leaving large cavities. Repairs, estimated to cost about $64 000, are about to be undertaken. The Norfolk Navy Yard dock, built in 1889, is now having the upper eleven altars renewed in concrete because of the decay, not only of the altars, but of the braces and pile heads which carry them. The wooden dry docks visited on the Lakes are in much the same general condition.

"'The speaker found that all engineers of the United States

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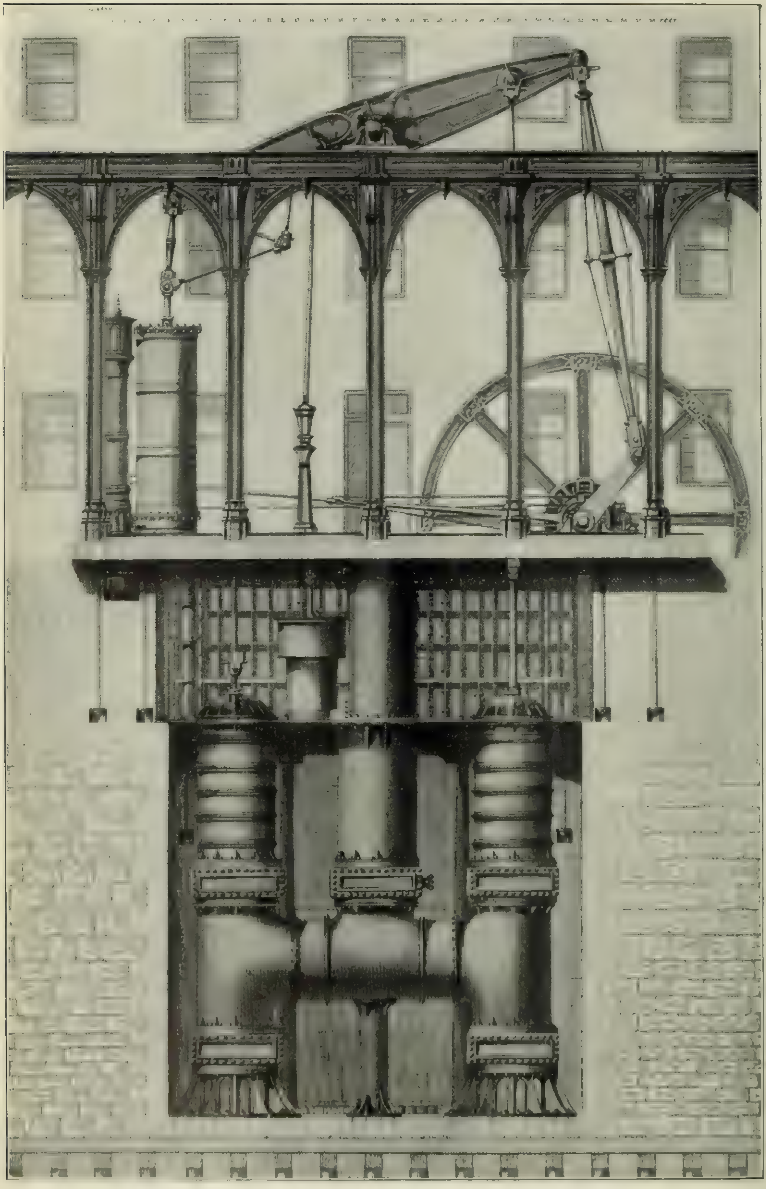
* "Dry Docks—Stone *vs.* Wood," *Transactions*, Am. Soc. C. E., Vol. XLI, p. 554.

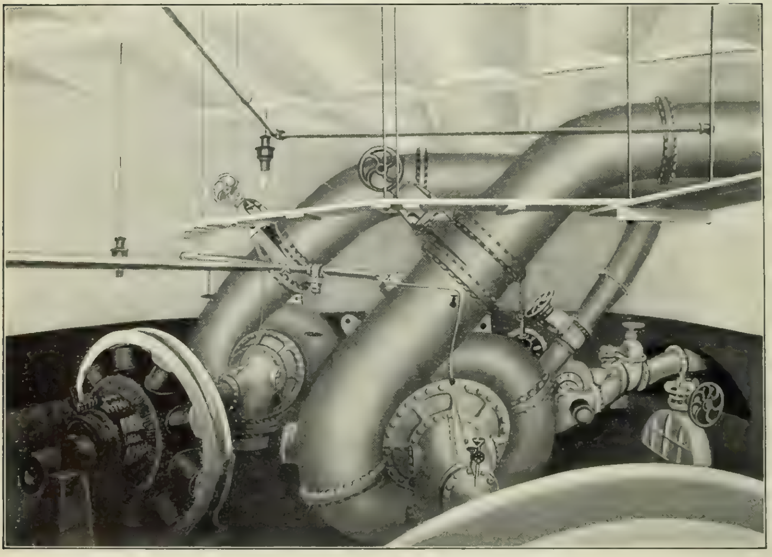
† John Kennedy, M. Am. Soc. C. E.

PLATE XLV. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
GOODRICH ON
DRY DOCKS,



OLD PUMPING ENGINE AT DRY DOCK NO. 1, NEW YORK NAVY YARD, INSTALLED IN 1854.

COMPARE WITH PLATE XLVI.



NEW ELECTRICALLY DRIVEN, CENTRIFUGAL PUMPING PLANT AT DRY DOCK NO. 1, NEW YORK NAVY YARD. COMPARE WITH PLATE XLV.

Navy Department who have had experience in the working and **Mr. Goodrich.** maintenance of wooden dry docks, and with whom the question was discussed, were understood to be quite against wooden dry docks, at least for naval use, because of their weakness and short life. On the other hand, private owners of wooden docks are in favor of wood for their own service, and in adding a new dock they build either wholly or mainly of wood. The obvious difference of conditions will account for much of the difference of opinion. In Government docks a small saving in first cost is of minor importance, but weakness and frequent need of repairs are well nigh intolerable. On the other hand, in docks of private ownership, saving in first cost is usually of serious importance, while the cost of maintenance repairs is met by the earnings of the dock, and is less felt. It is to be noted, however, in the more recent private docks built by owners of experience, that there is a desire for something more permanent than wood. A notable instance is that of the large dock now being built by the Newport News Shipbuilding & Dry Dock Company, in which the abutments and wings are to be of concrete. * * *

"'In Canada there are no wooden dry docks of importance. * * * All are of excellent limestone ashlar, with concrete backing and inverts, and none have had any repairs of more importance than pointing, except in the caissons and other accessories.

* * * * * * * * *

"'The advantages in strength, durability and economy of maintenance of dry docks of stone, and of stone and concrete, over those of wood, have been ably and fully shown in the discussions presented; and, for the reasons just outlined, the speaker adds a plea for dry docks built almost wholly of concrete, as possessing much of the advantages of both.'

* * * * * * * * *

"In the matter of first cost, the experience of the Navy has been that in masonry docks last built it is large, but that those first built, comprising the dry docks at the Boston and Norfolk navy-yards, of the finest quality of cut granite, the cost was not as much, being in each case less than $1 000 000. * * *

"Extraordinary difficulties existed in the site of the New York dock, which were chiefly responsible for its cost of $2 000 000. The Mare Island dock, although in an excellent site, cost $2 750 000.* As shown further on, however, we are now building dry docks very much larger than either of these, and better equipped, for little more than $1 000 000 each. * * *

"The timber docks for the Navy were all built by contract * * *.

"An opportunity has been afforded recently for instituting a somewhat accurate comparison of the relative costs of these two types of dry dock by the proposals received for the construction of concrete and stone dry docks designed for the Boston, Mass., and Portsmouth, N. H., navy-yards. Bids for these dry docks were based upon conditions very similar to those which obtained in the cases of the timber dry docks * * *. Upon the receipt of these bids contracts were entered into for the construction of both of these dry docks, which are to be among the largest in the world, the

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* Both were built by days' labor.

Mr. Goodrich. best and most extensive in their appointments, and the most substantial in their construction, at a cost of $1 013 400 in the case of the Boston dock, and $1 089 000 for the one at Portsmouth. * * * The cost of the timber dry docks * * * averaged about $540 000 for those built.

"Furthermore, the recent contracts for the timber dry docks at the Mare Island and League Island navyyards afford much more accurate comparisons with the masonry docks now building, because all are to be built by contract after competitive bids received within a few months of each other, under the same market conditions, and all are of the same general dimensions, and the same general equipment. The timber dry docks at Mare Island and League Island have been let at $729 000 and $782 600, respectively.

* * * * * * * * *

"The result is, of course, beyond dispute, and so favorable to the masonry dock as to be of the greatest value and significance. It shows that the relative costs of these works heretofore claimed by the advocates of the timber dry dock and generally accepted by the public were wrong and misleading.

* * * * * * * * *

"In weighing the relative merits of the stone and timber dry docks in the matter of convenience for use, the conditions are practically the same.

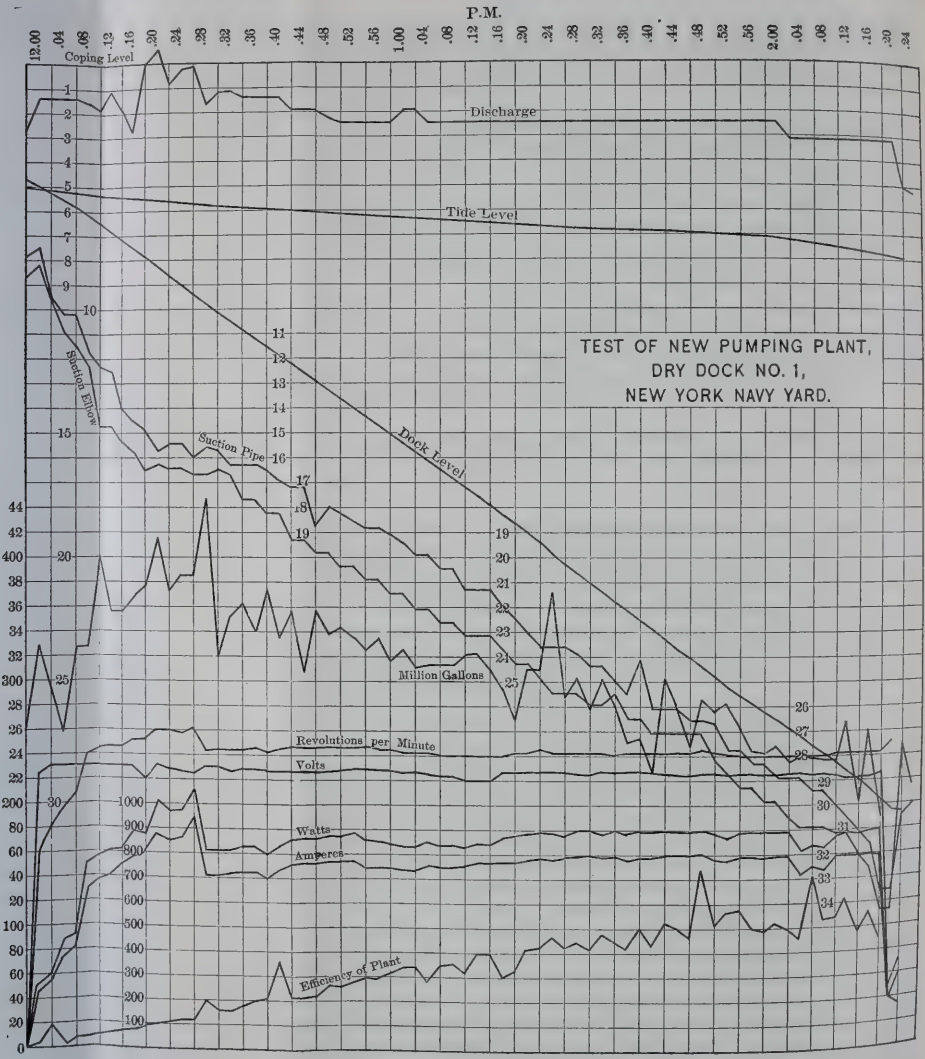
* * * * * * * * *

"The estimation in which timber dry docks are held is well illustrated by the action of the German Government in regard to granting a subsidy to a large graving dock to be built at Bremerhaven. A dock of the largest size was projected, and the Government was ready to pay an annuity in order to have the use of the dock for naval purposes when occasion should require, but when it was met with a proposition to construct this dock of timber it declined to make the grant, and ultimately consented only upon condition that it should be built of masonry."

The two wooden docks last referred to have been converted into concrete and masonry docks, and the Navy is now permanently launched upon a policy of building only concrete structures for all those of the excavated type. The conversion of Dry Dock No. 2, New York Navy Yard, was by far the largest alteration which has ever been made in a wooden dry dock. Practically the only portion of the old structure left intact was the floor. The speaker was connected with this alteration throughout its whole course.

A line of 12 by 12-in. grooved and splined sheeting was driven along each side of the intended structure, in a cut made in the altars of the old wooden dock. This was possible because of the narrower top provided for the concrete dock. The earth was then excavated in front of these lines of sheeting down to bottom grade, and heavy braces were installed to withstand the earth pressure. Foundation piles were then driven for the side walls, and the latter were built entirely of concrete. The front upper corners of the altars were

Mr. Goodrich.



TEST OF NEW PUMPING PLANT,
DRY DOCK NO. 1,
NEW YORK NAVY YARD.

nosed with brass, and chafing timbers, to take the wedges driven behind the shores, were let into the faces of those altars needing them. This reconstruction work is shown in Figs. 1 and 2, Plate XLIV.* Mr. Goodrich.

During the past ten years, besides the change from wooden to masonry dry docks, and the commencement of the construction of large floating docks, the greatest improvement has been made in the substitution of electric power for the various other means of pumping docks formerly used. While several commercial docks had already made use of this power, notably the Morse Iron Works Floating Dock and those belonging to the Newport News Ship Building Company, the first application of it to naval docks was at Dry Dock No. 1, New York Navy Yard. At this point, the old walking-beam, low-pressure, single-cylinder engine, originally installed in 1854, was superseded by an electrically-driven, centrifugal pumping plant located entirely below the surface of the ground. The relative size of the old and the new plants is illustrated in Plates XLV and XLVI. A somewhat similar comparative view may also be seen in *The Scientific American* of March 24th, 1900. The old pumping engine is reproduced from Stuart's "Dry Docks of the United States," and the view of the new pumping plant is from a wash drawing made up from several photographs.

The capacity of the new plant is 60 000 gal. per hour (more than five times that of the old plant), and the official tests of the pumps were among the earliest known on centrifugal pumps of large dimensions. The curves of discharge, efficiency, etc., are shown in Plate XLVII, and are of importance principally in showing what a high efficiency is actually attained by such pumps where simply the pump itself is in question. The pressure-measuring pipes were tapped into holes drilled through the thick cast-iron suction and discharge pipes, about three diameters from their connection to the pump. The objection may be raised that the flow is likely to be irregular and to give excessive results at these points, but the percentage of error cannot be large enough to reduce the efficiency very much as the taps were at the center of the sides of the pipe in each case, while all bends in the large pipes in the vicinity of the pumps were vertical. It is interesting to note the increase in the efficiency as the head increases. The measurements of the discharge could be ascertained very accurately, as the dry dock structure had rather high altars, and the dimensions of the dock could be determined exactly.

A rough approximation only can be made as to the relative efficiencies of the old walking-beam pumping engine driven with 60 lb. steam pressure by old Martin boilers, and of the new electrically-driven plant, consisting of Babcock and Wilcox boilers, and cross-compound condensing engines driving 750 kw. generators. The total coal normally consumed by the former was said to be

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* A fuller description is to be found in *The Scientific American* of October 20th, 1900.

Ir. Goodrich. from 7 to 9 tons at each operation. The estimated total coal necessary to do the work at present is less than ¾ ton, based on 3 lb. of coal per kilowatt-hour for the power plant.

The similarly designed pumping plant for Docks Nos. 2 and 3 at the same yard, commenced three years ago under the speaker's direction, has not yet been completed by the contractors. Its preliminary test performance, however, gives a fair comparison. The present plant consists of high-pressure, steam-driven, balanced, centrifugal pumps, steam for which is supplied by Scotch marine boilers. The old coal consumption was 5 tons and the new consumption is 1½ tons.

All Naval Docks have pumps with balanced suctions, while all the commercial docks of which the speaker knows, which make use of electric drive, are side-suction pumps with vertical shafts, with the motors several feet above the pumps.

In the United States, as has been said, ship-shaped caissons are almost always used. In connection with the design of Dry Dock No. 4, New York Navy Yard, the speaker suggested to the Navy Department the use of a rectangular caisson. The suggestion was at first adopted, but the Department has since changed its decision. The only valid objection to such a caisson, as far as the speaker can determine, is its less relative stability at light draft, as noted by Mr. Brereton. On the other hand, the advantages are largely in its favor. The dock can be flooded either through the suction chamber at the bottom of the caisson, through the discharge pipes, or through the pumps themselves. In the latter case they would be run as impulse water wheels, and the motors would be converted to dynamos. It might be possible to store, in suitable batteries, the electric power thus generated, to be used again when it became necessary to pump the dock. With the pumping plant thus arranged, the suction and discharge pipes are very short, thereby saving power; the necessity of a special caisson drainage pump is obviated; and no pump-house, etc., is required.

Furthermore, no valid objection can be raised to the placing of the dock pumping machinery in such a caisson, except that of a much greater loss in case the caisson were wrecked or sunk for any reason. As suggested by Sir William White, if the caisson is made a sliding one, this objection is largely diminished. With such an arrangement, no costly culverts or discharge pipes are necessary, the caisson and dock drainage pumping machinery are combined in one pump, and the only extra cost in the dock is a slight increase in depth at the entrance so as to provide for removing all seepage by the caisson pumps.

The costs of work in France, as given by M. Joly, seem very small, compared with the cost of the dry docks with which the

Mr. Goodrich.

speaker is conversant in the United States, especially when account is taken of the methods of construction in the two countries. In the United States the excavation is almost invariably done in open cut, by dredges, or, occasionally, where rock is encountered, or bad digging, by open cut with derricks, travelers, etc.

In the construction of Dry Dock No. 4, New York Navy Yard, ample scope will be given for methods similar to those described by M. Joly, as the site selected is notoriously fraught with difficult conditions, and the adjoining docks are historical in the difficulties encountered during their construction.

As far as known to the speaker, compressed air has never been used in the United States in dry dock excavation because of its high cost, although the speaker knows that the matter has been investigated by various engineers. The use of patented freezing processes has also been suggested where the materials are of a nature hard to handle, but even the latter has not been used in dry-dock work, as far as known.

Docks in the United States, in rare instances, have rudder pits, as is sometimes the case abroad. This difference is probably entirely due to the difference in method of attachment of the rudder posts. For all large docks, traveling and other cranes are invariably in use, and, usually, compressed air, sometimes electric power and water supply are available for the use of vessels while in dock.

From several of the quotations given in this discussion, the actual costs of construction may be determined, and the following examples may be considered typical of the costs of such structures at the present time in the United States:

Wooden dry dock, of large size, with caisson and pumping plant....................	$ 750 000
16 000-ton steel floating dry dock..........	810 000
Concrete dry dock, of large size, in good bottom, with caisson and pumping plant..	1 100 000

Sir W. H. White

Sir William H. White, President, Inst. C. E., London, England. —It appears to the speaker that Mr. Timonoff's paper is an elaborate description of an old plan, the only new feature being the proposed use of loose stone dams with earth facings, instead of some other means of excluding water. Much of the detail into which the author enters seems unnecessary, and the circumstances under which the material suggested could be obtained are not of common occurrence. He also contemplates the use of pumping appliances in connection with improvised docks. Such appliances obviously are not commonly obtainable in outlying places where exceptional means of docking have to be improvised. He supposes, moreover, the vessel to ground upon a sandy bottom; but sandy bottoms are not always, ir W. H. White or often, to be found when accidents occur. Any one who has had to do with the repairs of ships knows that access to portions of the ship below the bilge is generally difficult on a sandy bottom, and it is often necessary to excavate in sections under the ship. With great respect to Mr. Timonoff, the speaker considers his proposal of little practical value, and thinks that he has not had much to do with practical docking of ships; in addition, his scheme assumes conditions of rare occurrence.

What has been said about the Chinese having long used mud docks is true. Officers of the British Navy, whose ships have needed repair, have entrusted the work to Chinese contractors who have constructed temporary mud docks by manual labour and carried out the work at moderate cost. The hole was formed, the ships floated in, the entrance closed, and the whole operation done by manual labor in a short time. It seems probable that the repairs at Port Arthur have been done more by coffer-dams than by any system of docking; the Russians are expert in coffer-dam work, and external repairs of considerable magnitude have been made in that manner. Speaking generally, while suggestions for temporary docks are interesting, we may well leave the people concerned to make the best use of the means which lie at their disposal.

A modern ship, especially a modern warship, obviously requires careful handling in docking. An armored ship with hundreds of tons of armor on her sides, and of great width, is built with a bottom that is comparatively an egg-shell, and, unless properly supported, there are enormous risks in docking such a structure. It is quite easy to crush up the bottom of such a ship unless great care is taken. The case of the U. S. Cruiser, *Columbia,* when docked at Southampton, is well known. The spacing of the blocks was just such as would have been practiced with ordinary merchant ships, but it was not suitable to the light structure of the warship and the results were anything but satisfactory. The speaker has been in the double bottom of a large ironclad docked in a Government dockyard in England, where, owing to want of care, certain portions of the structure were pushed up in relation to others, and the light framework at the bottom was squeezed in a very uncomfortable manner.

The ship designer, of course, must consider not only the condition of the ship afloat, but also that of the ship in dock; and the designer of the dock, on his side, must know something about the structure of the ships which he is accommodating and must make arrangements accordingly. In the *Great Eastern,* Brunel had to face the construction of a ship for which there were no dry or floating docks available. Mr. Brereton describes what Brunel did to provide for the cleaning and repair of the huge ship. He not merely made the bottom of the ship flat, but over it, where the plates were about 3 ft. wide, each strake of plating had a longitudinal frame upon it, so that the whole bottom was stiffened. The vertical bulkheads enclosing the coal bunkers, which were about two-thirds of the breadth of the ship apart, were extended up to a cellular deck, so that the ship was made into a complete tubular structure. She had, also, a cellular double bottom. Here is a case where the designer said: "I cannot have a dock available for my ship and must arrange accordingly." The ship used to be placed on a "gridiron" laid on a rocky foreshore in Milford Haven, which was levelled to give proper and uniform support, and there she was again and again repaired and cleaned. Sir W. H. White

M. Joly's paper is a very interesting one, especially from the point of view of the constructive engineer, it being the only paper presented on the subject that describes methods of construction. The summary given of the conclusions of the International Congress on Navigation held at Düsseldorf in 1902 as to the relative advantages of dry docks and floating docks, is very interesting, but the final words which refer to the question of commercial success are vital, in fact they contain the pith of the matter.

In England recently there was a discussion as to the relative advantages of the two systems in connection with the equipment of the dry docks at Gibraltar. The opponents of the site which was chosen outside the Mediterranean wanted to put the dockyard where it would be sheltered, from any attack from across the bay, by the Rock of Gibraltar, and, therefore, advocated floating docks. A special committee was appointed to consider this question, and it was the speaker's duty to give evidence before them. Not long before, he had recommended to the Admiralty the construction of the new Bermuda floating dock, so that this evidence expressed his opinion as to the merits of the two systems. For all the operations of a great naval arsenal, the balance of advantage lies, in the speaker's judgment, on the side of graving docks.

The cleaning and repairing of ships in graving docks below the ground level, as compared with floating docks where everything has to be hoisted, can be done more conveniently and certain risks are avoided. Mr. Goodrich has said that Governments are bound to have the best appliances for such works, and when the site permits of the construction of a graving dock, that is the better course. At Bermuda, local circumstances did not permit of the construction of a graving dock, unless an island of concrete had been made which would contain the graving dock. The cost would have been enormous, and there were no reasons for incurring it, because a floating dock could be placed in a berth alongside the dockyard, permanently attached to the shore by gangways and lifting appliances;

ir W. H. White consequently, that arrangement was adopted under the special circumstances. No one, unless he is extremely wrongheaded, would say that there are not conditions under which a floating dock is the better system. All recent floating docks of British construction have been designed by Messrs. Clark and Stanfield and built by Messrs. Swan Hunter and Upham Richardson on the Tyne. An American dock, similar to that at Bermuda, and designed by Clark and Stanfield, was built in America.

One thing about floating docks should never be overlooked, and it is not mentioned in any of these papers, *viz.*, the absolute necessity of ready access to all parts for cleaning and painting, including the outside. The old floating dock, which has been at Bermuda for something like forty years, was designed by a man who thoroughly understood the stability of floating bodies, and he made that dock so that it could be careened, by the admission of water on one side, until the middle of the bottom was brought above water. Mr. Campbell laid it down as an essential that there should be possibility of access for cleaning, painting and maintenance. It is a singular fact that, although this was done, that dock was not properly cared for during many years, although its location imposed the necessity for special care in cleaning and painting. At length it reached a condition, through neglect of ordinary precautions, which involved large expenditure for putting it in good order. After forty years, that dock is, however, still in good working order and very useful.

It is wonderful how these floating docks can be taken about the world. Two docks have been built for Durban. The first had been towed within 500 miles of Durban when a storm arose; the captain of the towing ship sought shelter and unfortunately failed to keep the dock off the shore where she was lost. The Natal Government gave an order immediately for a new dock, which was built in an unprecedentedly short time and is now at Durban. With ordinary care, these docks can be towed all over the world, and their use will extend.

M. Joly gives particulars of French docks, and what strikes the speaker most about these docks is their extreme narrowness for modern conditions. There is a reason for that because French designers, until lately, have favored narrowness of beam in ships, whereas, in England, we have favored greater breadth with fine extremities. Up to the present time, the French have had no ship that could not go into a dock 80 ft. wide, but in their latest designs they are approaching the English model more closely. It is that fact which makes M. Joly now endorse the conclusion which we have reached in England. He says: "For the future, it will be prudent to assume * * * dry docks with a least width of 30 m.

(98.4 ft.)." He thus shows his grasp of the subject. His paper, Sir W. H. White while it necessarily omits some details, is a valuable contribution, showing French practice and thought in relation to docks.

Mr. Brereton's paper, as he says, was intended to promote discussion, and it gives certain facts about later English docks, both commercial and Government, which will be of interest. The first-class dock approved by the British Admiralty at the present time is 800 ft. long, 100 ft. wide, with a depth of 30 ft. of water over the sill. In addition there are deep docks, which are often used as locks, into which ships drawing about 36 ft. can be brought. At Devonport, there are docks, 740 by 95 ft., and at Portsmouth there is 44 ft. of water at spring tides. Some time ago, after a collision between two German ships, one drawing 33 or 34 ft. of water, came into Portsmouth and was docked without difficulty.

Careful consideration of the depths of the dock sills in modern commercial ports is required with reference to the docking of the largest passenger steamers. Vessels like the new Cunard steamers ought to work at 33 to 34 ft. draft. The swiftest ships carry little freight and cannot be lightened much. The limit of lightening is determined by the stores and coal carried at sea. In designing these new Cunarders, it has been a governing condition to provide for dry docking, and this is generally true for the largest ships. The dock engineer and the ship designer, therefore, must be in close touch, and a good margin in draft of water on dock sills should be provided in all new works. Floating docks and dry docks must be considered together, as the scale of the one has relation to the scale of the other.

In English practice generally, the top of the blocks is not much above the sill, and there is usually a drainage "well" at the after end of the dock into which the side gutters run. The height of blocks is about 3 ft. 6 in., but sometimes, when large repairs are contemplated, ships are docked on high blocks. The tops of blocks are also kept very low when the damage is not below the bilge.

V. E. TIMONOFF, M. AM. SOC. C. E., St. Petersburg, Russia.* (By Prof. Timonoff. letter.)—The writer regrets that it was impossible for him to attend the Congress and take part in the discussion, in order to explain more fully the principal features of the system of temporary dry docks which he advocated. But he notes with satisfaction that his paper has been analyzed to a certain extent by those who took part in the discussion, and that the principal ideas expressed are in entire accord with his own.

Mr. Goodrich finds the system of rapid dry-dock construction proposed by the writer to be entirely feasible, and suggests that the pumps of the ship to be repaired be used to empty the dock, in place rof. Timonoff. of a special pumping plant which would not always be within reach. This appears to be an excellent idea and could be applied successfully in many cases.

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*Professor at the Institute of Ways of Communication, St. Petersburg, Russia.

Sir William H. White states that the new principle introduced by the writer, in this new system of dry docks, is the construction of loose stone dams with earth facings, and that the system thus planned can be applied only under special conditions which do not often occur. The writer thinks, however, that the number of seaports where stone and earth for building enclosed dikes and sand to form the foundations of dry docks may be found is large enough to warrant him in not sharing this opinion.

AMERICAN SOCIETY OF CIVIL ENGINEERS,
INSTITUTED 1852.

TRANSACTIONS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

RAILROAD TERMINALS.

Congress Paper No. 94.

BRITISH RAILROAD TERMINALS.

BY WILLIAM THEODORE FOXLEE, M. INST. C. E., London, England.

Congress Paper No. 95.

FRENCH RAILROAD TERMINALS.

BY ERNEST PONTZEN, COR. M. AM. SOC. C. E., Paris, France.

Congress Paper No. 96.

REVIEW OF GENERAL PRACTICE.

BY ELMER L. CORTHELL, M. AM. SOC. C. E., New York City, U. S. A.

Discussion of the Subject by

ALBERT P. GREENSFELDER, St. Louis, Mo., U. S. A.
WILKIE WOODARD, Cincinnati, Ohio, U. S. A.
GEORGE W. PARSONS, Steelton, Pa., U. S. A.
E. E. R. TRATMAN, Chicago, Ill., U. S. A.
S. G. HOMFRAY, London, England.
W. M. CAMP, Chicago, Ill., U. S. A.
ROBERT MOORE, St. Louis, Mo., U. S. A.
CHARLES L. MORGAN, London, England.
ELMER L. CORTHELL, New York City, U. S. A.

NOTE.—Figures and Tables in the text are numbered consecutively through the papers and discussion on each subject.

TRANSACTIONS

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 94.

RAILROAD TERMINALS.

BRITISH RAILROAD TERMINALS.

By William Theodore Foxlee, M. Inst. C. E.

In this paper it is proposed to give particulars of some of the principal terminal station works which have been carried out during the past ten years, and which may be regarded as typical examples of present British practice. The space available, however, will only admit of dealing with a few of the more important stations, but it is hoped that at the Congress the paper will assist in raising a discussion on this important branch of railway engineering which cannot fail to be of interest to all who are connected with the construction, maintenance and working of railways.

The examples which have been selected are as follows:

Terminal Works at Ports.

1.—Southampton Docks. London and South Western Railway.
2.—Barry Docks. Barry Railway Company.
3.—Heysham Harbour Station. Midland Railway.

TERMINAL WORKS INLAND.

4.—Marylebone Terminus. Great Central Railway.
5.—Liverpool Street Terminus. Great Eastern Railway.
6.—The Bank Terminus. Central London Railway.
7.—Victoria Station. London, Brighton and South Coast Railway.
8.—Waverley Station, Edinburgh. North British Railway.
9.—Paragon Station, Hull. North Eastern Railway.
10.—Deansgate Goods Depot, Manchester. Great Northern Railway.
11.—Aston Goods Depot, Birmingham. London and North Western Railway.
12.—Blackpool Stations. Lancashire and Yorkshire Railway.
13.—Crewe Station. London and North Western Railway.
14.—Waterloo Station. London and South Western Railway.

TERMINAL WORKS AT PORTS.

Southampton Docks. London and South Western Railway.—The docks at Southampton, which are owned by the London and South Western Railway Company, are at the head of Southampton Water, between the Rivers Test and Itchen. They form the terminus of the company's cross-channel and over-sea traffic, and are about 78 miles from London. They were owned by a private company originally, and were opened for traffic in 1843, passing into the hands of their present owners in 1892. Since that date, large extensions and improvements have been carried out to meet the increased requirements of the traffic, and these include practically the whole of the works upon the area reclaimed from the River Test and on the western side of the Empress Dock. (See Plate XLVIII.)

The docks consist of three wet and five dry docks, to which a sixth will soon be added. It is not proposed to enter into the details of construction, but to describe briefly the general arrangements for dealing with the traffic between the railway and the steamers, which is all that can be done within the limits of this paper.

The old passenger terminus of the company is on the northern

PLATE XLVIII. VOL.
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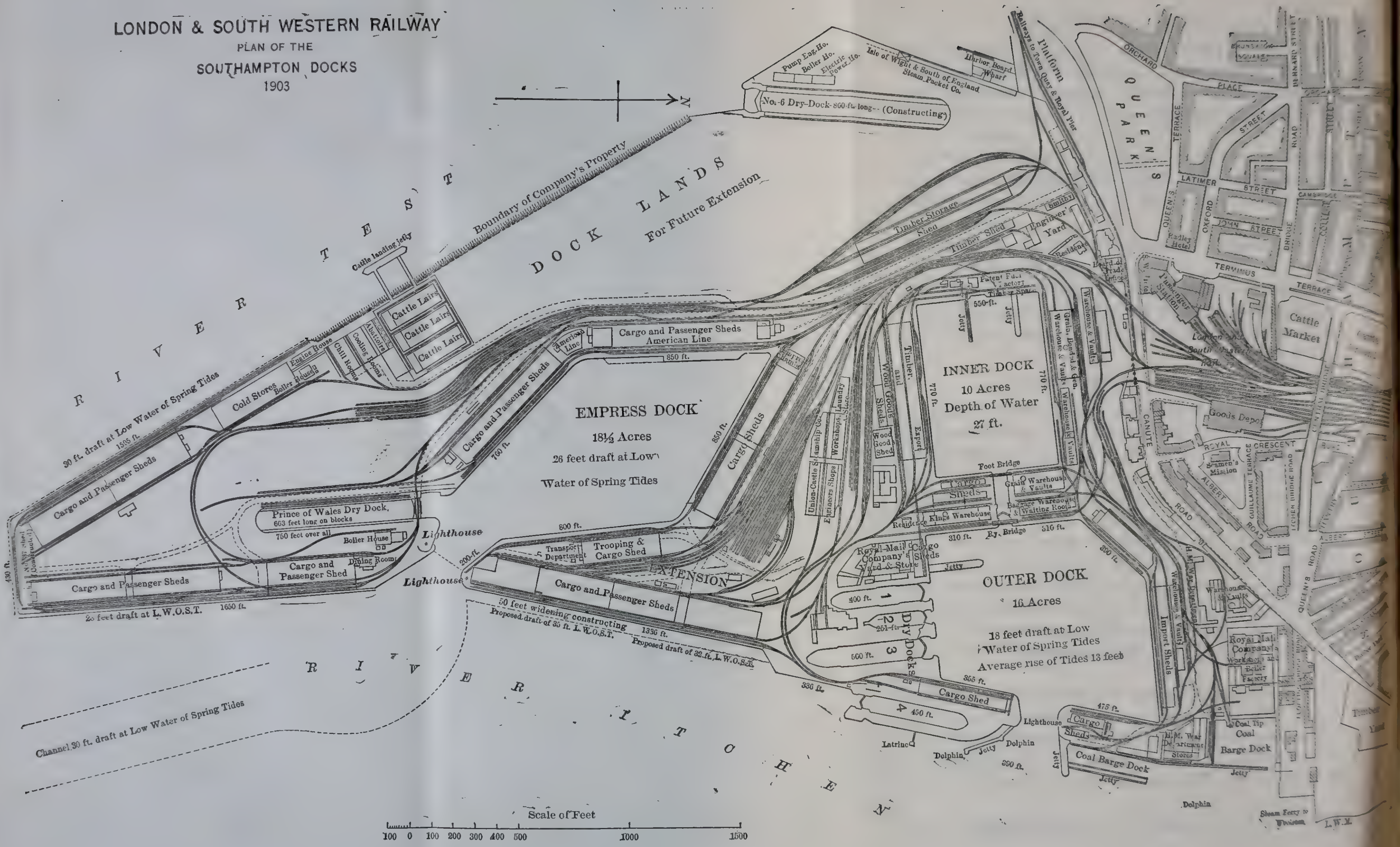
FOXLEE ON
BRITISH RAILROAD TER



LONDON & SOUTH WESTERN RAILWAY
PLAN OF THE
SOUTHAMPTON DOCKS
1903

side of Canute Road, and is connected with the docks by lines which are continued over that road on the level, and which pass around the various quays and alongside the steamers, enabling passengers and goods from all parts of the kingdom to be transferred from railway to steamer without inconvenience or exposure.

Owing to the situation of the Isle of Wight at the head of Southampton Water, the docks, besides being easy of access from the Metropolis, have the unusual advantage of double tides, which gives a period of 4 hours of high water at every tide, the limit of range being about 13 ft., thus enabling ships to enter or leave at any hour of the day or night.

There are three wet docks, *viz.:*

The Empress Dock,	area	18½	acres,	draft	26 ft.	at L. W. O. S. T.
" Outer Dock,	"	16	"	"	18 "	"
" Inner Dock,	"	10	"	"	27 "	"

In addition to these there are six graving docks of the following dimensions:

No. 1.—400 ft.	long by	66 ft.	wide.
No. 2.—251 "	"	51 "	"
No. 3.—500 "	"	80 "	"
No. 4.—450 "	"	56 "	"

The Prince of Wales' Dock is 750 ft. long by 90 ft. wide at the entrance, and has a depth over the blocks of 32 ft. 6 in. at H. W. O. S. T., and 29 ft. at H. W. N. T.

No. 6 Graving Dock, now in course of construction, is of the following dimensions:

Length....................	851 ft. 9 in.
Width at quay level	125 ft.
Width at entrance..........	90 ft.
Depth over blocks..........	H. W. O. S. T., 33 ft. 6 in.
" " "	H. W. N. T., 30 ft.

This dock, which is being carried out from the designs of W. R. Galbraith, M. Inst. C. E., the London and South Western Company's Consulting Engineer, is constructed throughout of Portland cement concrete with granite quoins and steps. The entrance gates, which are of steel, are opened and closed by direct-acting hydraulic rams.

The engine-house contains two 48-in. centrifugal pumps for emptying the dock, and these are driven by direct-acting vertical engines which are served by seven boilers of the locomotive type.

Adjoining the engine-house, and served by the same set of boilers, is the new power-house, which is being built to replace a smaller one, and from which the current required for lighting, as well as the power for the electric cranes, lifts, and elevators throughout the docks, will be obtained.

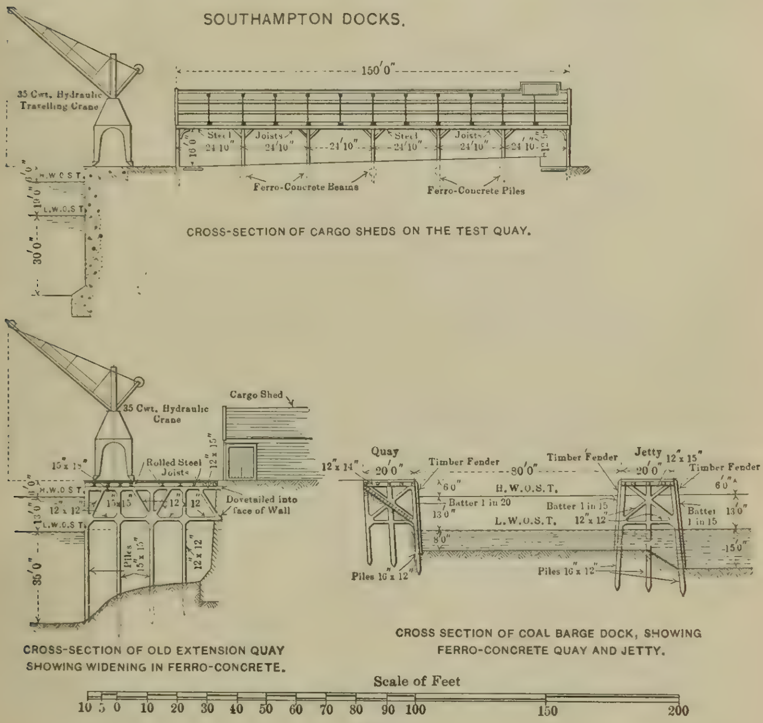
An approach channel to this dock, 600 ft. in width and 30 ft. in depth at L. W. O. S. T., has been dredged in the River Test.

In addition to the docks mentioned there are four quays, known as the "Old Extension Quay," having a length of 1 336 ft. and a depth of 20 ft. of water at L. W. O. S. T.; the "Prince of Wales' Quay," 1 650 ft. long, with a depth of 28 ft. at L. W. O. S. T.; adjoining the latter is the "South Quay," 430 ft. long, with a similar depth of water; and the "Test Quay," running northward for a distance of 1 595 ft., having a depth of 30 ft. at L. W. O. S. T.

The Old Extension Quay is on the east side of the Empress Dock. It is about 1 300 ft. in length, and has 20 ft. of water at L. W. O. S. T. This quay is now being widened in ferro-concrete, as shown by Fig. 1, to 50 ft. The decking consists of wood-block paving set on timber planking 4 in. thick, laid diagonally on timbers supported by rolled-steel joists. Line of way for trucks and hydraulic traveling cranes of 30 cwt. capacity are also being put down. The depth of water will be increased to 35 ft. in order to accommodate vessels of deep draft.

Spacious transit sheds, for export and import cargoes, which are for the most part one story high, 120 ft. in width, and built of timber, are conveniently placed alongside the various quays. The latter are about 35 ft. in width, and have double lines of rails served by hydraulic cranes, of 35 cwt. capacity, for loading and unloading vessels. At the back and inside of the sheds run other lines of rails for the purpose of bringing trains alongside and under cover. A section of this arrangement is shown by Fig. 1.

The cold store and foreign animals wharf, recently opened for the reception of imported food products, and believed to be the largest and most complete in Europe, is at the northern end of the Test Quay. The foundations of the cold store building are carried on ferro-concrete piles, the ground having been reclaimed from the River Test. More than 1 100 piles, 14 by 14 in. in section and 42 ft. in length, were used for this purpose. The building, which is also constructed of ferro-concrete, is 400 ft. long, 120 ft. wide, and 46 ft. 4 in. high, the basement being 4 ft. 3 in. below quay level. It contains five floors, with provision for putting on two additional floors later. The basement has a clear headway of 10 ft., and is divided into fourteen rooms, ranged on each side of a corridor 11 ft. 2 in. wide, and has two reception galleries with band conveyors connected with the quay. The ground floor contains ten rooms, with 14 ft. headway, similarly ranged along a central passage, and has a loading platform extending throughout the whole length of the building, alongside which runs a line of rails, for the purpose of bringing refrigerator vans and railway wagons into the store. The first and second floors each contain


SOUTHAMPTON DOCKS.

CROSS-SECTION OF CARGO SHEDS ON THE TEST QUAY.

CROSS-SECTION OF OLD EXTENSION QUAY SHOWING WIDENING IN FERRO-CONCRETE.

CROSS SECTION OF COAL BARGE DOCK, SHOWING FERRO-CONCRETE QUAY AND JETTY.

Fig. 1.

sixteen rooms, with a central corridor, the former floor having a headway of 14 ft. and the latter of 10 ft. A third floor has been added, but is at present temporarily covered in and used for receiving and distributing cargoes. The building, which has a storage capacity of about 1 750 000 cu. ft., is cooled by the ammonia process, and is equipped with every modern appliance for handling goods economically. The fittings, which were supplied from the designs of Messrs. Bramwell & Harris, comprise:

Four direct-coupled electric goods lifts, to raise 30 cwt. each;
Two electric sheep, or barrel, elevators, having 30 cradles each;
Eighteen electric fans for air circulation.

On the ground floor there is a complete system of overhead tracking and hangers.

On the north side of the cold store are the engine- and boiler-houses, which are also built of ferro-concrete. The equipment consists of:

Four double-acting De la Vergne compressors, of 60 tons capacity, with steam engines;
Two surface condensers, each dealing with 13 200 lb. of steam per hr., with single-acting air-pumps;
Three Worthington compound condensing engines, each delivering 30 000 gal. per hr.;
Three combined electric generating sets, Siemens-Brotherhood, shunt-wound dynamo, 72 kw. at 220 volts;
Three Babcock and Wilcox water-tube boilers, with mechanical stokers and a coal-conveying plant;
And a 5-ton overhead hand-power traveling crane.

To the north of the engine- and boiler- house is the foreign animals wharf, with lairs which will accommodate 1 500 head of cattle. In connection with these there are abattoirs, cooling and chill rooms, directly communicating with one another, and also, by means of a covered way, with the cold store. The jetty for landing cattle, at which there is a depth of water of 30 ft. at

L. W. O. S. T., is 200 ft. long by 38 ft. 4 in. wide, and is connected with the lairs by two runs, 142 ft. 6 in. long by 15 ft. wide.

The works, which are lighted throughout by electricity, and which were carried out under the writer's supervision, are connected with the dock sidings and thereby placed in direct communication with the whole railway system of the kingdom.

In the northeast corner of the docks there are two coal docks capable of floating 14 000 tons in lighters, at one time, for bunkering purposes. The coal comes from South Wales, either in trucks or in colliers, and is handled in each case by the most modern machinery. One of the enclosing jetties has recently been constructed of ferro-concrete on the Hennebique system from designs by the writer. This material was adopted owing to the fact that timberwork at Southampton is subject to the attacks of marine organisms and soon perishes. The jetty is 20 ft. wide at its deck level, and 300 ft. in length. A section of it and the adjoining quay, which is also constructed of ferro-concrete, is shown by Fig. 1.

On the northern and eastern sides of the Inner Dock are brick warehouses for the storage of grain, with a total capacity of about 2 000 000 bushels. The grain is unloaded by elevators, and conveyed to the various warehouses by a system of band conveyors of the most modern description, electrically driven, and capable of dealing with 200 tons of grain per hour.

Large warehouse accommodation for the storage of merchandise of every description, and commodious vaults and stores around the Inner and Outer Docks are also provided, and are convenient of access from road, rail, and steamer.

Two timber sheds, 600 by 117 ft., and 800 by 100 ft., respectively, are provided to the south of the Inner Dock and between it and the new graving dock.

The crane equipment is as follows:

9 20-cwt. hydraulic cranes.
6 30-cwt. "
20 35-cwt. "
12 5-ton "
2 5-ton hand-cranes.
1 7-ton "

1 10-ton hand-crane.
3 30-cwt. steam cranes.
2 5-ton steam traveling cranes.
1 12-ton "
1 30-ton "
1 50-ton electric traveling crane.
Shears, 80 tons lift.
" 20 tons lift.
3 coal transporters.

The dock sidings have a total length of about 29 miles. Those between the Empress Dock and the cold store are used for storage, and those between the former and the Inner Dock, for marshaling purposes. The total area of the dock estate is about 230 acres, and the total length of the quays about 15 427 ft. or nearly 3 miles.

Besides the ships of the Union Castle, American, Royal Mail and other Lines which make Southampton either their terminus or port of call, the London and South Western Railway Company runs regular services of steamers to the Channel Islands, Havre and St. Malo, and Government transports leave at irregular intervals.

Barry Docks.—The docks at Barry, in South Wales, are on the north and east sides of Barry Island, about 9 miles southwest of Cardiff. They are the property of the Barry Railway Company, and were constructed, practically, for the sole purpose of dealing with the shipment of coal, though a large quantity of timber is now imported. It will be seen from the plan, Plate XLIX, that they consist of two docks and a basin. They possess the advantage of having their entrance in a well-sheltered position and close to deep water. No. 1 Dock was opened for traffic in 1889, and has an area of 73 acres, divided at the western end by a mole 1 300 ft. long by 200 ft. wide, with a depth of water of about 38 ft. at H. W. O. S. T. No. 2 Dock was opened in 1899, and has an area of 34 acres, with a similar depth of water. Besides these docks there are two graving docks and two timber ponds, the areas of the latter being 35 and 6 acres, respectively. The Barry Company also owns lines of railway connecting directly with the most important coal fields in South Wales.

The coal shipment takes place on the north sides of both Nos. 1 and 2 Docks, and on each side of the mole within the former. The

PLATE XLIX. VOL. LIV. PART E
TRANS. AM. SOC. CIV. ENGRS.
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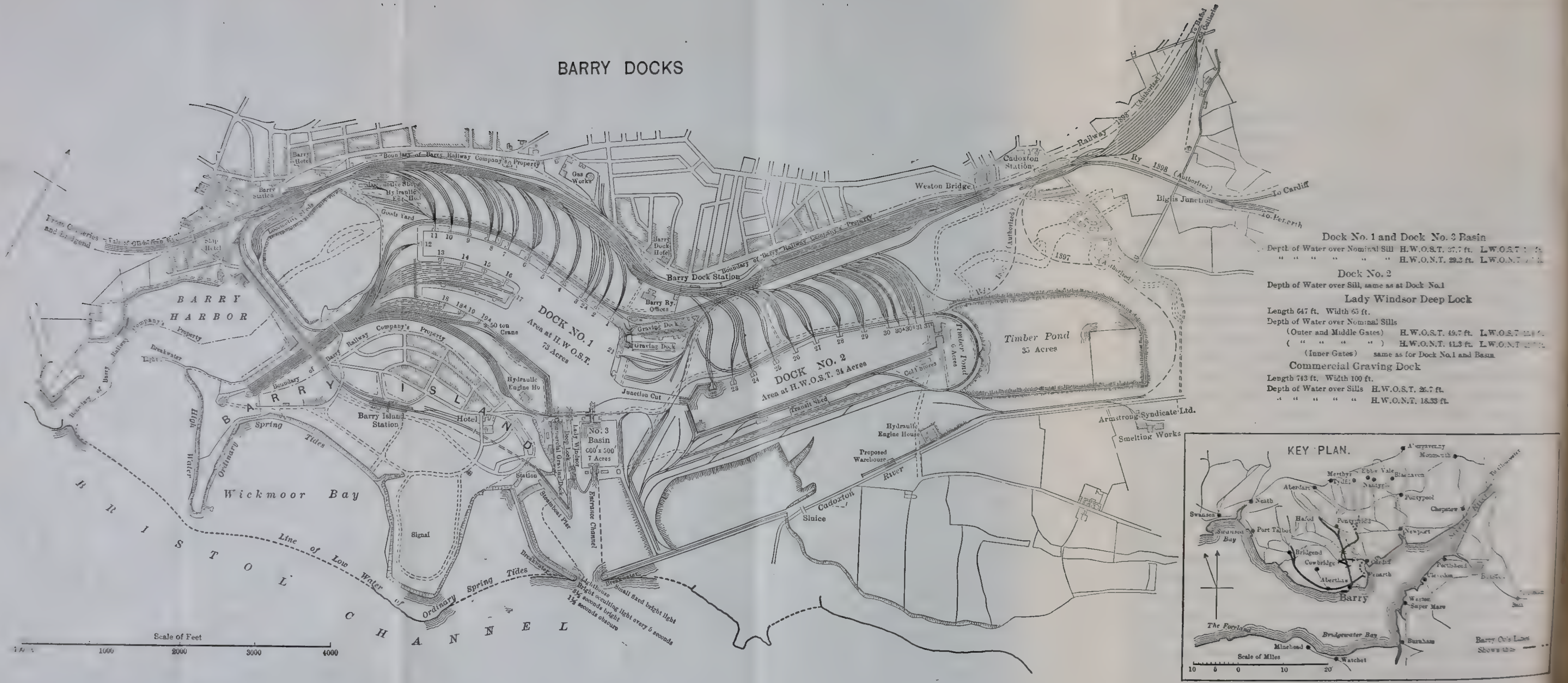
BRITISH RAILROAD TERMINALS

BARRY DOCKS



Dock No. 1 and Dock No. 3 Basin

Depth of Water over Nominal Sill H.W.O.S.T. 37.7 ft. L.W.O.S.T. [illegible]
" " " " " H.W.O.N.T. 29.2 ft. L.W.O.N.T. [illegible]

Dock No. 2

Depth of Water over Sill, same as at Dock No. 1

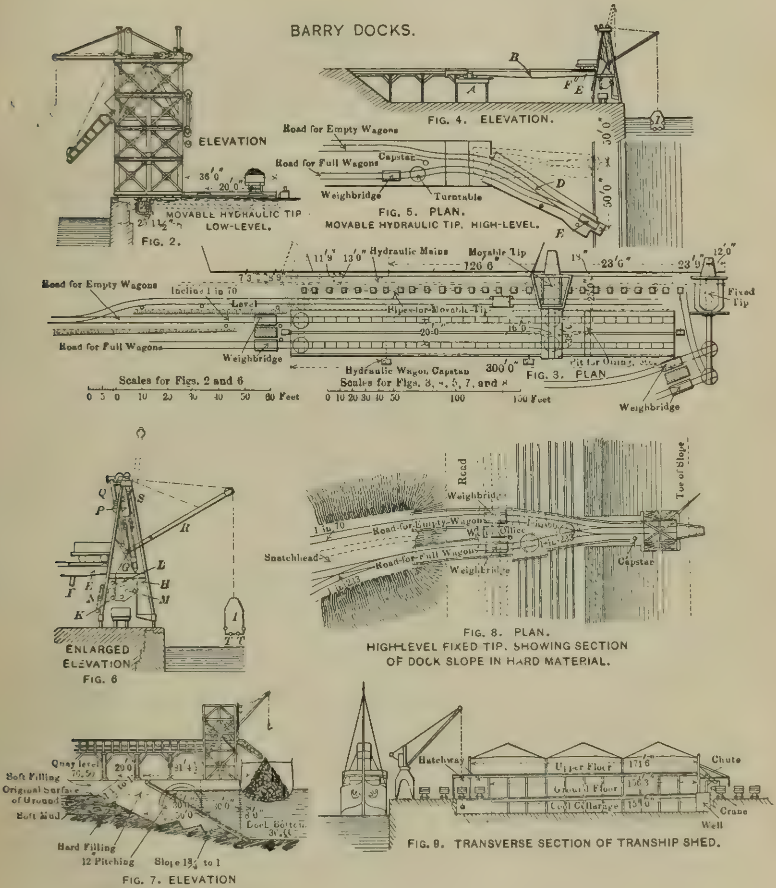
Lady Windsor Deep Lock

Length 647 ft. Width 65 ft.
Depth of Water over Nominal Sills
(Outer and Middle Gates) H.W.O.S.T. 49.7 ft. L.W.O.S.T. [illegible]
(" " " ") H.W.O.N.T. 41.3 ft. L.W.O.N.T. [illegible]
(Inner Gates) same as for Dock No. 1 and Basin

Commercial Graving Dock

Length 743 ft. Width 100 ft.
Depth of Water over Sills H.W.O.S.T. 26.7 ft.
" " " " " H.W.O.N.T. 18.33 ft.

south sides of both docks are reserved for the import trade, for which ample sidings, sheds and warehouses are provided, the timber traffic being dealt with at the eastern end of No. 2 Dock. The coal is loaded into the vessels by tips (see Figs. 2 to 9), of which there



BARRY DOCKS.

ELEVATION MOVABLE HYDRAULIC TIP LOW-LEVEL. FIG. 2.

FIG. 4. ELEVATION.

FIG. 5. PLAN. MOVABLE HYDRAULIC TIP. HIGH-LEVEL.

FIG. 3. PLAN

Scales for Figs. 2 and 6

Scales for Figs. 3, 4, 5, 7, and 8

ENLARGED ELEVATION FIG. 6

FIG. 8. PLAN. HIGH-LEVEL FIXED TIP, SHOWING SECTION OF DOCK SLOPE IN HARD MATERIAL.

FIG. 7. ELEVATION OF HIGH-LEVEL FIXED TIP.

FIG. 9. TRANSVERSE SECTION OF TRANSHIP SHED.

are thirty-eight, thirteen belonging to No. 2 Dock, and the remainder to No. 1. In the former case they are all on the high level, three of them being movable. At No. 1 Dock there are nine fixed and three movable tips on the low level, and eleven fixed and two movable tips on the high level. The fixed tips are erected at distances varying from 174 to 300 ft. apart, so as to accommodate vessels of varying lengths between hatchways. The lifts of the tips are 32, 42 and 45 ft., and their capacity 20 tons. The maximum quantity shipped by one tip per hour is 490 tons, and as many as 44 000 tons have been put on board in one day of 24 hours. By using two movable and one fixed tip an exceedingly quick rate of loading can be obtained, and it happens not unfrequently that, for the period of an hour or more, 1 wagon per minute is tipped. It is stated that a steamer has entered the docks, shipped 1 900 tons of coal, and left on the same tide; and that coal in the seam at the Ocean Colliery in the morning has been hewn, conveyed, and on its way down Channel in the evening of the same day.

The method of working the tips is as follows: On the high level the wagons are brought upon curved sidings, having a gradient of 1 in 233, leading to the tips; they are then drawn forward to a weighbridge, and thence to the tip one by one by hydraulic capstans. The lifting cradles, together with their guides and framing, are carried on masonry work 30 ft. square, and are worked by direct-acting hydraulic rams. The tip-table is worked by a hydraulic cylinder carried on trunnions fixed to girders underneath the cradle. The first discharge of coal is made into an anti-breakage cage or box, which is raised to the lower end of the shoot by a hydraulic lift or turning crane, and the box when full is lowered into the hold and discharged, the process being repeated until a cone of sufficient height is built up to avoid the breaking of coal falling from the shoot. When this cone is formed the box is swung out of the way, and the coal is loaded down the shoot in the ordinary manner. After it has been tipped, and the cradle returned to its proper level, the empty wagon is pushed away, down an incline of 1 in 80, to a second weighbridge, where the tare is obtained; thence it goes down a 1 in 70 gradient to sidings, where the empties are collected into trains and removed by engines up a 1 in 45 slope to other sidings provided for the purpose. Some of the tips have two lines of way, which, besides providing an additional storage for coal of one quality, are also intended for wagons filled with coal from different pits, so that ships can load with any desired blend. On the low level the wagons are drawn forward down a gradient of 1 in 140 to a weighbridge, and thence, by means of a turn-table, to the cradle, whence they are raised and tipped. After tipping, the wagons run on a second weighbridge to obtain the tare weight, and then down a 1 in 70 incline to sidings on the level, from which they are taken away by engines.

The framework of the hoists is of wrought iron, 57 ft. high, and carries a shoot for the discharge of coal. The lifting is accomplished by two rams of 11¼ and 6⅛ in. diameter, respectively, with a direct-acting stroke of 37 ft. On the return stroke the large ram exhausts freely, while the smaller one returns to the accumulator. The same arrangements are observed here as on the high level to prevent the breakage of coal.

On the southern side of No. 2 Dock a large tranship shed has been erected, a transverse section of which is shown by Fig. 9. It consists of a cool cellar with two floors above. The cellar has an uniform width of 155 ft. The floor above is 156 ft. 3 in. wide and 496 ft. long. The top floor is 171 ft. 6 in. wide, including an unroofed platform, and is of the same length as the floor below. There are bonded stores and the best facilities for storing and handling grain, general produce, and all kinds of imported goods, the shed being efficiently equipped with cranes and traversers.

At the southeast corner of the docks an ice factory and cold store, capable of holding 30 000 carcases, has been built, with provision for extension to double its present capacity.

All the machinery in the docks is actuated by hydraulic power supplied from fourteen accumulators at a pressure of 750 lb. per sq. in. There are three power-houses, fitted with nine pairs of horizontal surface-condensing engines, indicating 250 h. p. per pair, and supplied with steam from twenty-five Lancashire boilers at a pressure of 80 lb. per sq. in.

Wagon capstans are provided on all wharves and tips, while, for the discharge of cargo, and for repairs, etc., the following cranes are available:

43 hydraulic ballast and timber cranes. (Movable.)
4 " (Fixed.)
1 50-ton hydraulic fixed crane.
1 steam floating crane.
1 10-ton steam traveling crane.

4 5-ton steam traveling cranes.
1 3-ton "
1 12-ton hand traveling crane.
1 1½-ton "
1 2-ton "
1 1½-ton hand fixed crane.

Extensive engine sheds, and fitting and repairing shops, equipped with the latest appliances, are provided at the northeast corner of the docks, and near the Dock Station the new offices of the company are situated, consisting of a three-story building covering an area of more than 2 000 sq. yd.

The total length of the company's lines is 62 miles, besides 132 miles of sidings, of which 100 miles are in and around and connected with the working of the docks.

In conclusion, it may be stated that the exports of coal have increased from 1 076 061 tons in 1889, to 8 810 127 tons in 1903; and it may be interesting to note that in 1884, when the company obtained their Act for the construction of the first dock, the population of Barry was only 100, and that it has since grown to 30 000.

Heysham Harbour Station. Midland Railway.—Fig. 10 is a general plan of the new port at Heysham, in Morecambe Bay, which is being created by the Midland Railway Company for the purposes of its steamer traffic between England, the Isle of Man, and the North of Ireland, where it has recently acquired the Belfast and Northern Counties and other Railways. When the works are opened, it is expected that, by this route, Belfast will be brought within about 12 hours of London.

The terminal arrangements for dealing with the traffic to and from the steamers may be briefly alluded to, although they are not yet complete.

The harbour itself is in the form of a parallelogram, about 2 400 ft. long by 700 ft. wide, and covers an area of about 36 acres, protected by breakwaters thrown out from Red Nab in the south and from Near Naze in the north. The mouth of the harbour is about 300 ft. wide, the area enclosed being approximately 140 acres. The total area of the company's dock estate is about 500 acres, which leaves ample room for future extension. The rise and fall

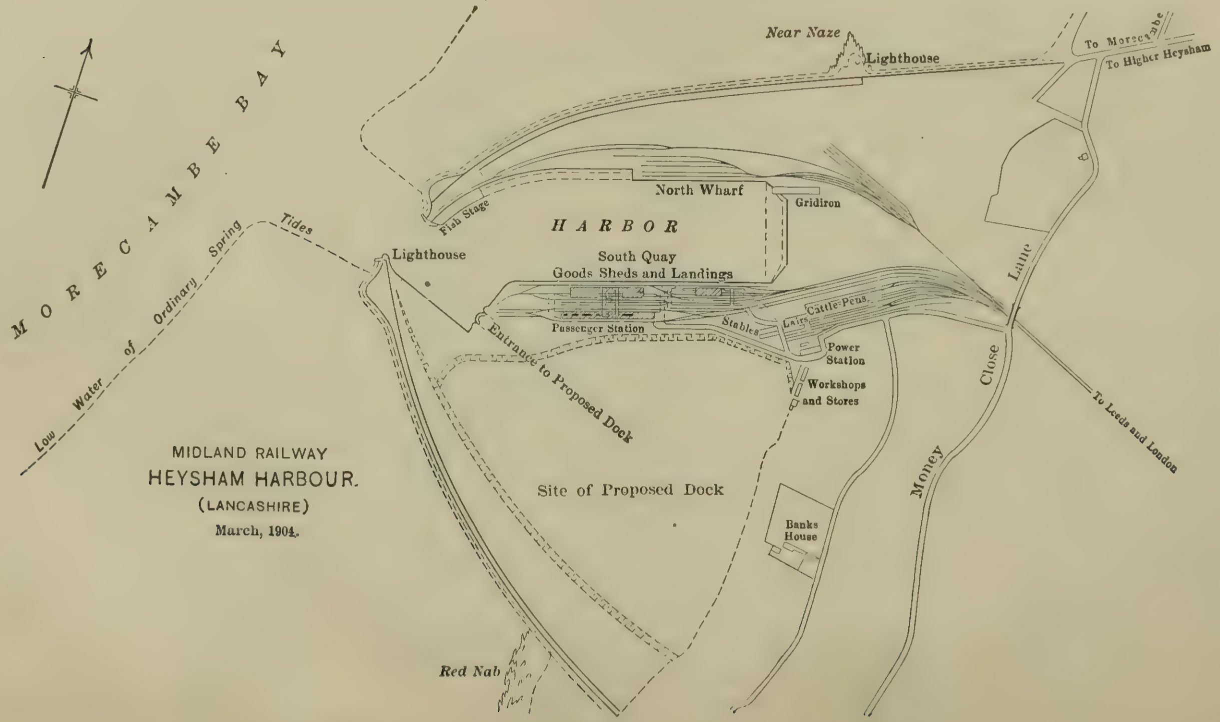
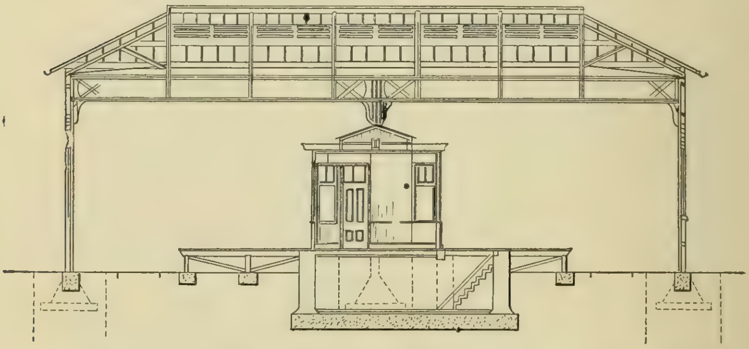

MORECAMBE BAY
Low Water of Ordinary Spring Tides
MIDLAND RAILWAY
HEYSHAM HARBOUR.
(LANCASHIRE)
March, 1904.
Lighthouse
Fish Stage
North Wharf
Gridiron
HARBOR
South Quay
Goods Sheds and Landings
Passenger Station
Stables
Lairs
Cattle-Pens.
Power Station
Workshops and Stores
Entrance to Proposed Dock
Site of Proposed Dock
Banks House
Red Nab
Near Naze
Lighthouse
To Morecambe
To Higher Heysham
Money Close Lane
To Leeds and London

FIG. 10.

of the tide here is between 24 and 27 ft. A substantial three-decked landing-stage, therefore, has been constructed along the whole length of the southern side, giving a minimum depth of water of about 17 ft. at L. W. O. S. T. Upon this quay, provision is made for dealing with both passenger and goods traffic.

The passenger station consists of a single island platform, with waiting- and refreshment- rooms, lavatories, booking hall and parcels office. The roof is carried on three rows of columns, and extends over the lines serving the platforms, as shown by Fig. 11, the buildings being of timber. An over-bridge and subways connect the platform with the quay and landing-stages.



TRANSVERSE SECTION THROUGH PASSENGER STATION, HEYSHAM HARBOR.

FIG. 11.

The goods warehouses (equipped with electric cranes) and the sidings for goods are between the passenger station and the quay, the cattle pens and sidings, near which the power-house, workshops, stores and stabling are being put up, being laid down a little to the eastward.

On the northern side of the harbour another quay and more sidings are provided, for dealing with iron ore traffic, and, close to the Round Head, on the same side, a stage has been erected to accommodate the landing of fish from trawlers at any state of the tide.

Electric power will be used throughout the docks for lighting, cranes, and lifts. Three vertical gas engines, using the Mond gas,

PLATE L. VOL. LIV. PART F.
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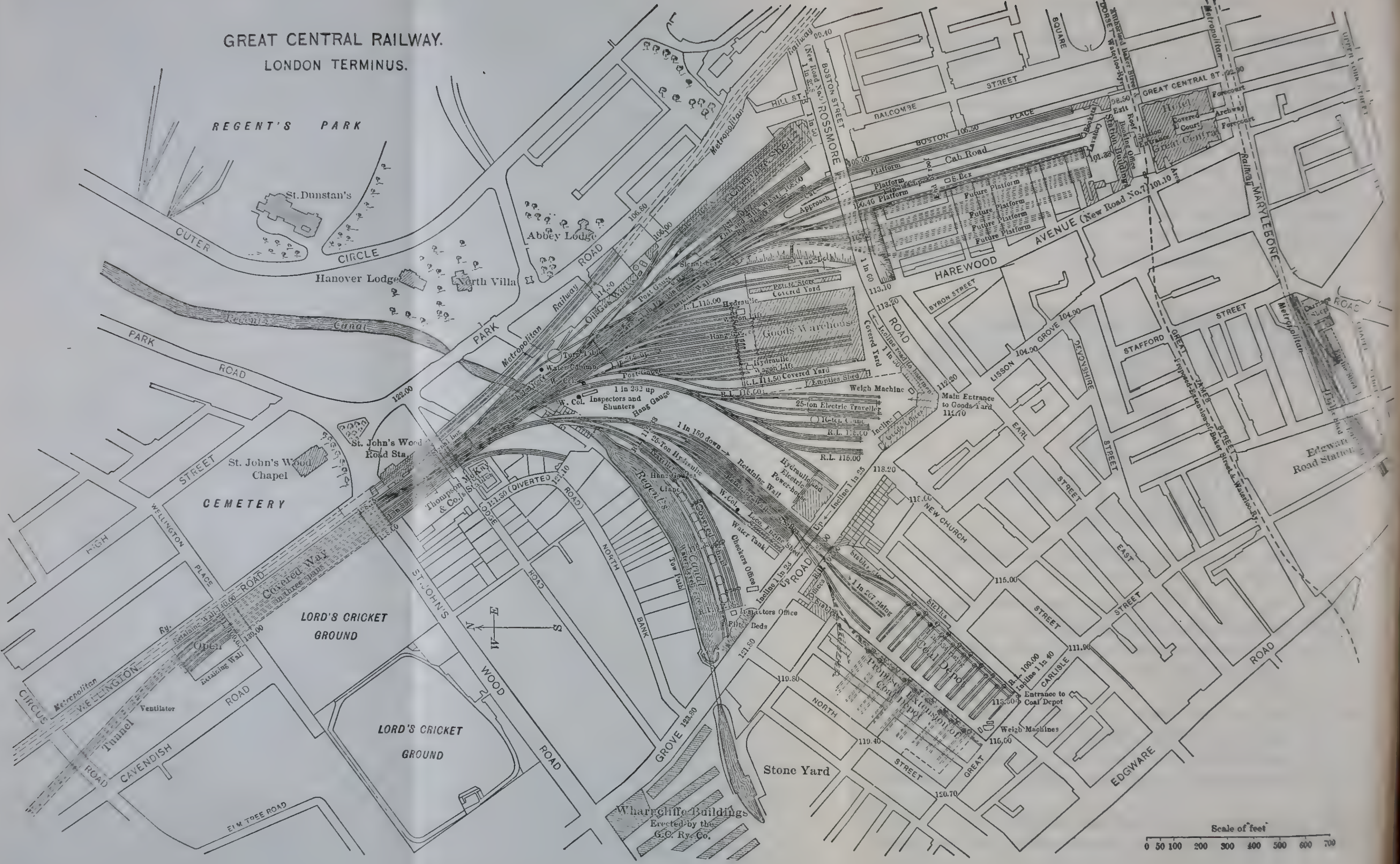
INTER. ENG. CONG., 1904.
FOXLEE ON
BRITISH RAILROAD TERMINALS.

GREAT CENTRAL RAILWAY.
LONDON TERMINUS.

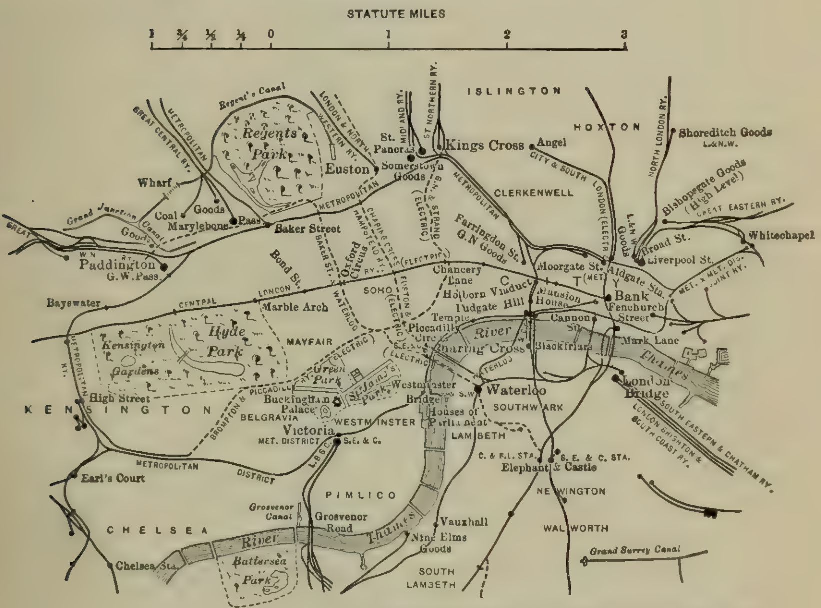


are to be installed, and each engine will be direct-coupled to a generator giving 150 kw. at 460 volts.

TERMINAL WORKS, INLAND.

Marylebone Terminus. Great Central Railway.—This station, which forms the terminus of the Great Central Railway extension to London, is, as will be seen from the diagram of London Terminal Stations, Fig. 12, situated in the northwest of the Metropolis, immediately west of Regent's Park, between Paddington Terminus of the Great Western Railway, and Euston Terminus of the London and North Western Railway. The works were carried out under the powers granted by Parliament in an Act which received the Royal assent on March 28th, 1893, and were completed in 1899. Therefore, as this is quite a recent example of a terminal station

MAP OF LONDON SHOWING TERMINAL STATIONS



Electric Tube Railways in Course of Construction are in Dotted Lines.

FIG. 12.

for a great trunk line, it is proposed to describe it somewhat in detail.

The yard, which comprises an area of about 51 acres (see Plate L), commences on the southern side of Lord's Cricket Ground, beneath which it passes in a covered way. After crossing under St. John's Wood Road, the seven lines of way branch out into fourteen lines, at the point where the Regent's Canal is crossed. These lines may be divided into five groups. The first section serves as the main track to the passenger station; the second division leads to the goods sidings and warehouse; the third curves sharply westward and runs to a wharf and transfer shed alongside the canal; the fourth group proceeds down a gradient of 1 in 100 to a coal depot; and the fifth runs to the carriage shed (which has accommodation for 64 carriages 45 ft. long), and to fish and milk landings.

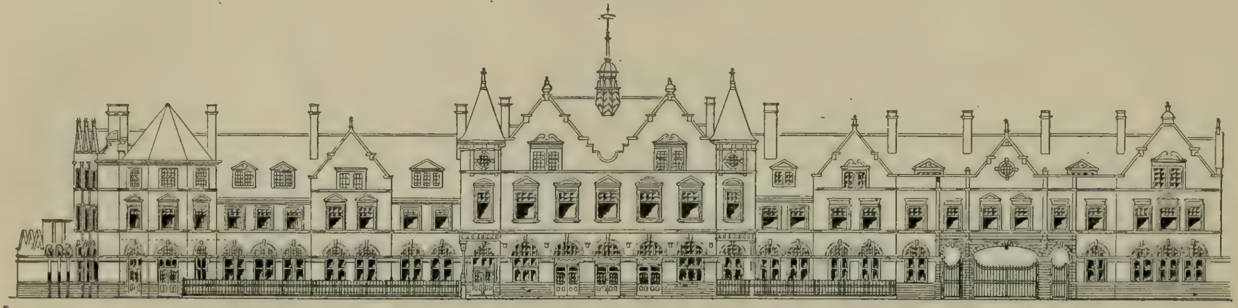
At present only five lines of way enter the passenger station, but provision has been made for ten more. The two arrival platforms, 950 ft. long and 25 ft. wide, are on either side of the cab road, and one double platform, 30 ft. wide and 950 ft. long, serves for departure trains. The platforms, which are 3 ft. in height, as well as the circulating area, are paved with 2-in. artificial stone in flags 2 ft. 6 in. square.

The passenger station is at the same level as the surrounding streets. It is approached by a 60-ft. roadway on each side of the Great Central Hotel, which stands in front of it. Between the hotel and the station there is a roadway 90 ft. in width, with a covered approach under which passengers alight on arriving at the station. These roadways are paved with wood blocks.

The station buildings have a frontage of 341 ft. facing south, with two wings extending northward, and adjoin a circulating area, 290 ft. long by 100 ft. wide.

The platforms extend for a distance of about 1 000 ft. at right angles to this circulating area, and are roofed over for a distance of 495 ft. Between the two eastern platforms, which are used for arrival trains, there is a cab road, 30 ft. wide, running the entire length of the station to the exit on the eastern side of the hotel. Empty cabs enter the station by an incline from the Rossmore Road, at the north end of the station.

TERMINAL PASSENGER STATION,
GREAT CENTRAL RAILWAY,
METROPOLITAN DIVISION,
(EXTENSION TO LONDON).



FRONT ELEVATION.

Scale of Feet
0 5 10 20 30 40 50

FIG. 13.

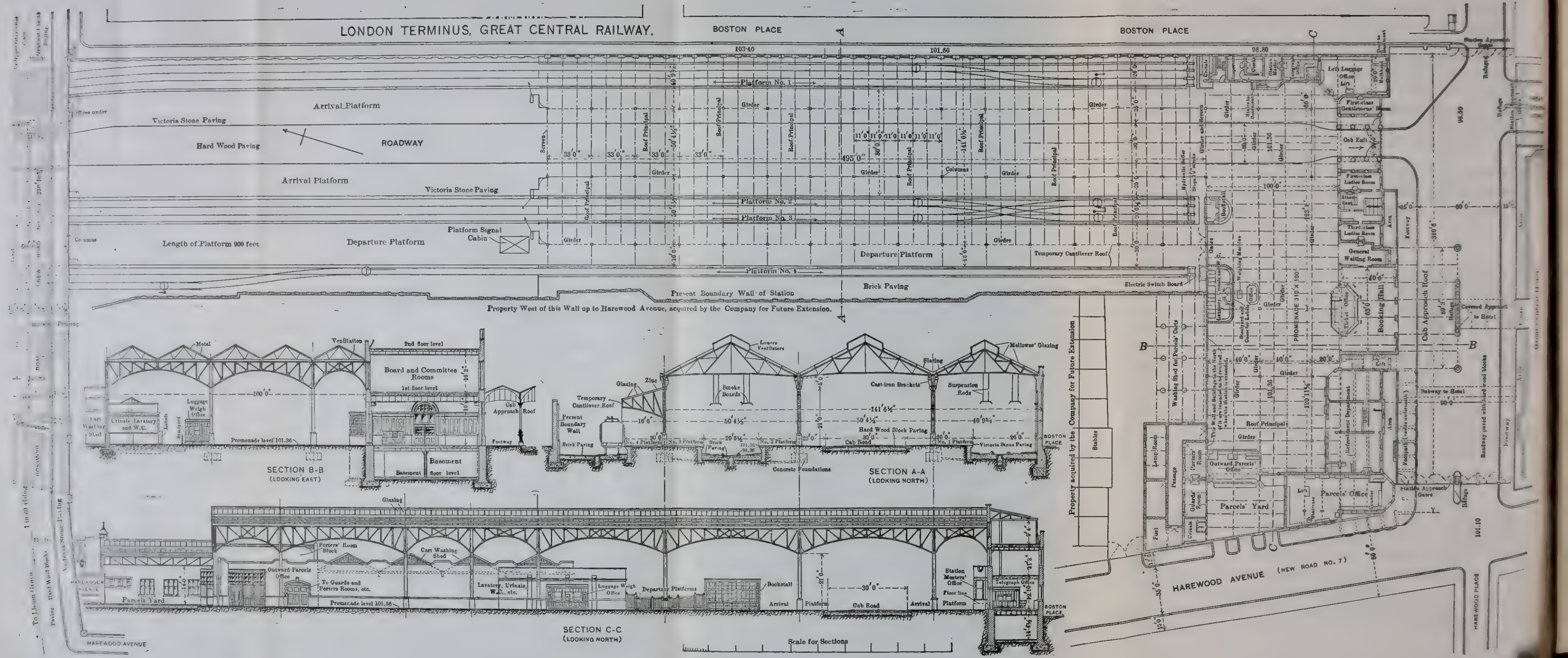
The first and second floors of the station buildings are arranged as offices for the various administrative departments, and the basement, which runs the whole length of the building, is used for stores. The area occupied by the buildings is 19 540 sq. ft. Details of the roofing are shown by Fig. 13 and Plate LI. The greater portion is glazed with ¼-in. plate glass carried on iron bars covered with tin-lead. No putty, or other means of fixing, was used. All the gutters are of cast iron, and are provided with snow-boards. The total area of roofing is 108 420 sq. ft., and the weight of steel and cast iron used is 1 055 tons.

The lines of way leading to the goods yard and warehouse diverge into ten tracks, laid in pairs, with a roadway between each pair. Two of the lines are served by a Goliath electric crane capable of lifting 25 tons at a rate of 5 ft. per min. The crane has a span of 60 ft., and a clear headroom of 21 ft., its total weight being 75 tons.

The warehouse is a four-story building, 390 ft. long by 261 ft. 6 in. wide, externally, with an average height of 82 ft. 9 in. above the basement floor. Its total capacity is about 8 500 000 cu. ft. The area of the ground floor is 2¼ acres, and the total floor area is 471 160 sq. ft., without the vaults, which have an area of 12 950 sq. ft., and a capacity of 133 357 cu. ft. The ground floor is approached by a road rising 1 in 50 from the main entrance to the yard. There is also a cart road on a gradient of 1 in 30 descending to the basement. The ground floor is divided into two portions, one for outward and one for inward traffic. Each half is served by three lines of way, grouped together, which enter the building from the north side and traverse almost its entire length. The work of shifting and hauling the wagons is done almost entirely by twelve capstans and six traversers. The capstans are arranged 120 ft. apart, in two rows, one on each side of the middle pair of rails. Platforms, 350 ft. long by 20 ft. wide and 3 ft. 9 in. high, have been built on each side of both groups of rails, and beyond the platforms there are cart roads. On the platforms there are twenty-four cranes in all, of which twenty are of 25 cwt., and four of 50 cwt. capacity.

The basement is 16 ft. below the ground floor, and is laid out with lines of way furnished with capstans and turn-tables. The

PLATE LI. VOL. LIV. PART
TRANS. AM. SOC. CIV. E
INTER. ENG. CONG., 19
FOXLEE ON
BRITISH RAILROAD TERM



LONDON TERMINUS, GREAT CENTRAL RAILWAY.

pavement throughout is of granite setts laid on 9 in. of concrete. The wagons are lowered by two hydraulic lifts of 20 tons capacity. The three floors above are arranged identically, and are used for warehouse purposes. They are not partitioned in any way, and have been designed to take a load of 3 cwt. per sq. ft. Two stone stairways built into the walls give access to the upper floors at opposite ends of the building. The walls encasing the stairways are carried up above the level of the roof, and form two water-towers with a capacity of 10 500 and 12 000 gal., respectively. The tanks communicate with automatic sprinklers on each of the floors, so that, should the temperature rise above 150° fahr., the sprinklers would open and quench the incipient outbreak of fire. Nine large openings have been arranged in each of the floors, measuring 43 by 24 ft., to give light from the roof and for raising and lowering goods.

The floors are supported on ninety continuous columns, 78 ft. 3 in. long, of steel joists and plates, the load per column being approximately 800 tons, which is distributed so as to give 3 tons per sq. ft. on the London Clay. The floors are supported by plate girders of the uniform depth of 2 ft. 9 in. The roadways are carried on steel flooring, concreted, and paved with wood blocks. In each of the upper floors the cross-girders are spaced 12 ft. apart, and rest alternately on the columns and longitudinal bearing girders. The floors are formed on top of the girders, with 11 by 3-in. timber joists spaced at 2 ft. 3 in. centers and laid with 7 by 2½-in. grooved planks tongued with iron.

The roof consists of sixteen 24-ft. spans with the ridges running across the building. About one-fifth of the roofing is glass, the remainder is close boarding and slate. The gutters are of cast iron, 27 by 11 in. in section, with the fall from the center toward the sides of the building.

The walls are of red brick, faced with pressed red and blue brick in the more exposed parts. Cement mortar was used, up to ground floor level, and lime mortar above. The total weight of steelwork used, including the platforms, was 6 963 tons.

The transfer shed, next the canal, is 520 ft. long by 92 ft. wide, the roof consisting of two cantilever spans of 26 ft. and one central span of 40 ft. Six cranes are provided, four with a lifting capacity of 30 cwt. and two of 50 cwt., and immediately to the east of the shed there is a hydraulic traveling crane of 25 tons capacity.

The coal yard is on the opposite side of Grove Road as shown. Stabling, fitted for 114 horses, has also been built, and the yard is lighted throughout by electricity.

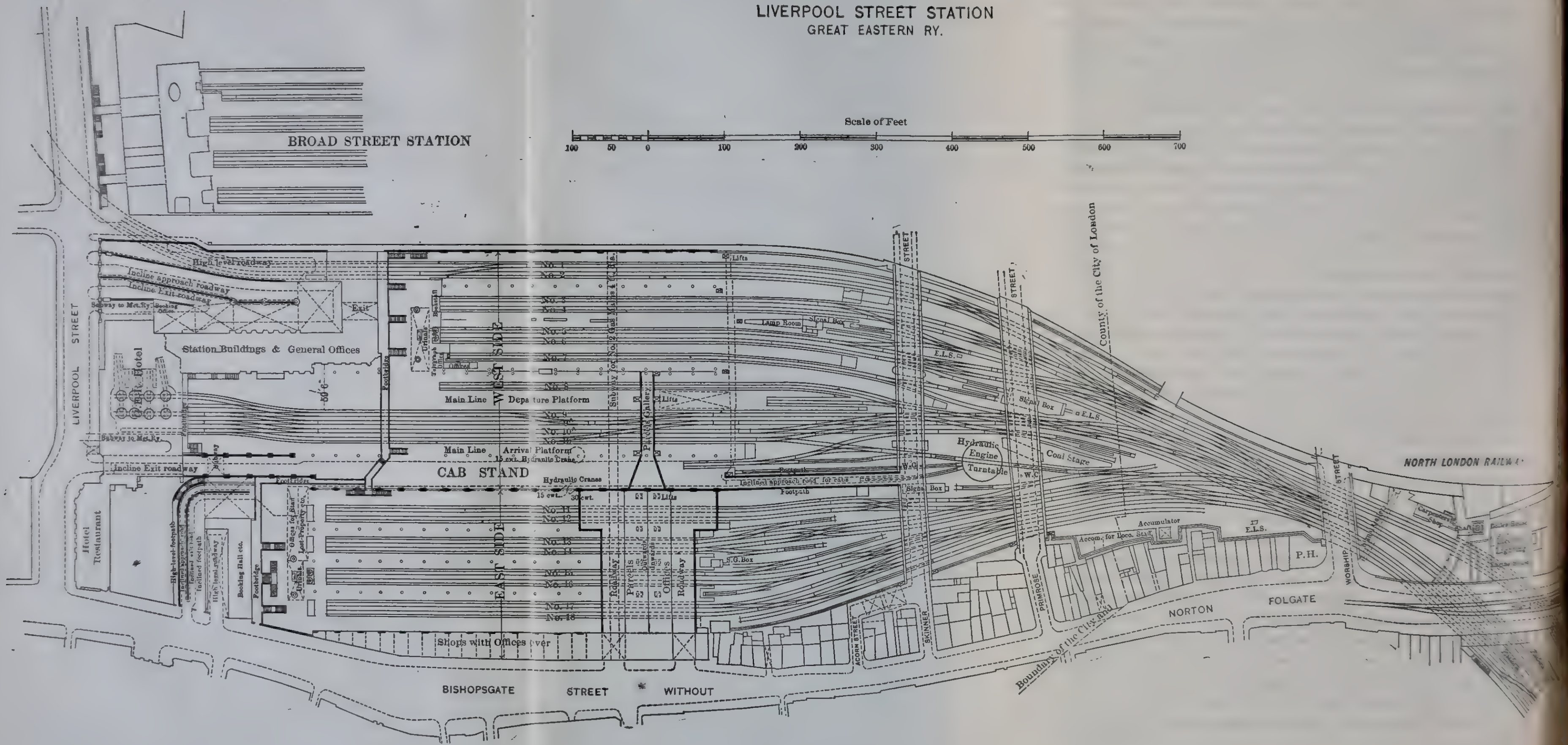
The power-house for both electric and hydraulic supply is 114 ft. long by 90 ft. wide, and is divided into three rooms. The first is the engine-room, 26 by 72 ft., containing the electric plant of eight direct-driven dynamos running at 385 rev. per min., and giving about 95 h. p. each. The second is the boiler-room, 60 by 57 ft., containing five Lancashire boilers of 400 h. p. each. The remaining room is fitted up with hydraulic plant, working at a pressure of 750 lb. per sq. in.

Liverpool Street Terminus. Great Eastern Railway.—The original terminus of the Great Eastern Railway was situated at Bishopsgate, about 1 mile northeast of the present station, and was used for both passengers and goods. With the growth of traffic, the site was found to be too small and inconvenient for dealing with both classes of traffic, and it was decided to extend the line, and build a more commodious terminus nearer the heart of the City, converting the old terminus into a goods depot. Liverpool Street was the site finally decided upon, and the first portion of the station, *viz.,* that on the western side of the cab stand (see plan on Plate LII), covering an area of 9¾ acres, and having nine platforms, was opened for traffic on February 2d, 1874.

The rapid growth of the company's suburban traffic has necessitated a further extension on the east of the cab road, out to Bishopsgate Street Without, adding another 6¼ acres to the terminus and bringing up the total area to 16 acres, and the number of platforms to eighteen. This additional area was opened for traffic on April 1st, 1894. Although the first portion of the station at Liverpool Street does not come properly within the limits of this paper, the enlargement completed in 1894 involved the remodelling of the working of the whole station, and, therefore, it is thought that it will be of interest to describe the latter as it exists to-day, particularly because by far the largest passenger traffic in the Metropolis is there dealt with.

The terminus is approached by six lines of way, arranged in pairs

LIVERPOOL STREET STATION
GREAT EASTERN RY.



under the names of Main, Local, and Suburban Lines. These six lines expand into twenty roads, eighteen of which are served by platforms, while the remaining two run in as sidings between the main line arrival and departure platforms. Platforms Nos. 1 to 6 are used for the suburban traffic, both for departure and arrival. Platforms Nos. 7 and 8, and Nos. 12 to 18 are used for local traffic. Of the remaining platforms, No. 9 is the main departure, No. 10 the main arrival, and No. 11 is used for both arrival and departure main line trains.

About half the area of the station is roofed in, namely, 180 000 sq. ft. on the west side, and 88 000 sq. ft. on the east side.

The western side of the station, *i. e.,* the older portion, is divided from the eastern half by the main cab road already referred to, which runs throughout the length of the station alongside the main line arrival platform, and has its entrance in Skinner Street and its exit in Liverpool Street. Besides this there are also two other cab approaches from Liverpool Street to the same side of the station; one is at street level, that is, about 17 ft. above platform level, and is reserved for suburban traffic; the other is inclined, and runs down to platform level, being used for main line traffic.

There are seven platforms on this side of the station: Starting from the west side, the first is a single platform (No. 1), 12 ft. wide. The next is a double one (Nos. 2 and 3), 25 ft. wide, carrying a single row of columns; the third is double (Nos. 4 and 5), 20 ft. wide; the fourth is single (No. 6), 12 ft. wide; the fifth is double (Nos. 7 and 8), 30 ft. wide, carrying a double row of columns 5 ft. apart; the remaining two (Nos. 9 and 10) are the main line platforms, and are 30 ft. wide throughout the greater part of their length, which is about 800 ft. Platforms Nos. 1 to 8 are about 600 ft. long. At their southern end there is, between them and the station buildings, a width of 80 ft., which, with Platform No. 9, forms a circulating area of 16 016 sq. ft., their total length being 7 610 ft.

The roofing over the west side (see section on Fig. 14) is divided into four spans of 45, 109, 109 and 43 ft., respectively. The roof principals are of lattice construction in the 109-ft. spans, having the bottom booms built to an elliptical arch. The shorter spans are of plate-girder construction, also elliptically arched. The principals are carried on ornamental cast-iron columns, which run down the middle of the platforms and are connected by segmental arches of plate-girder work. Where the long spans meet, the columns are double, and are spaced 5 ft. apart. The height of the columns is 35 ft. 6 in., and the apex of the roof is 74 ft. 9 in. above platform level in the larger, and 58 ft. 6 in. in the smaller spans. In both cases the spandrils are filled with ornamental ironwork.

About 1 079 tons of wrought iron and 1 460 tons of cast iron were used in the construction of this roof.

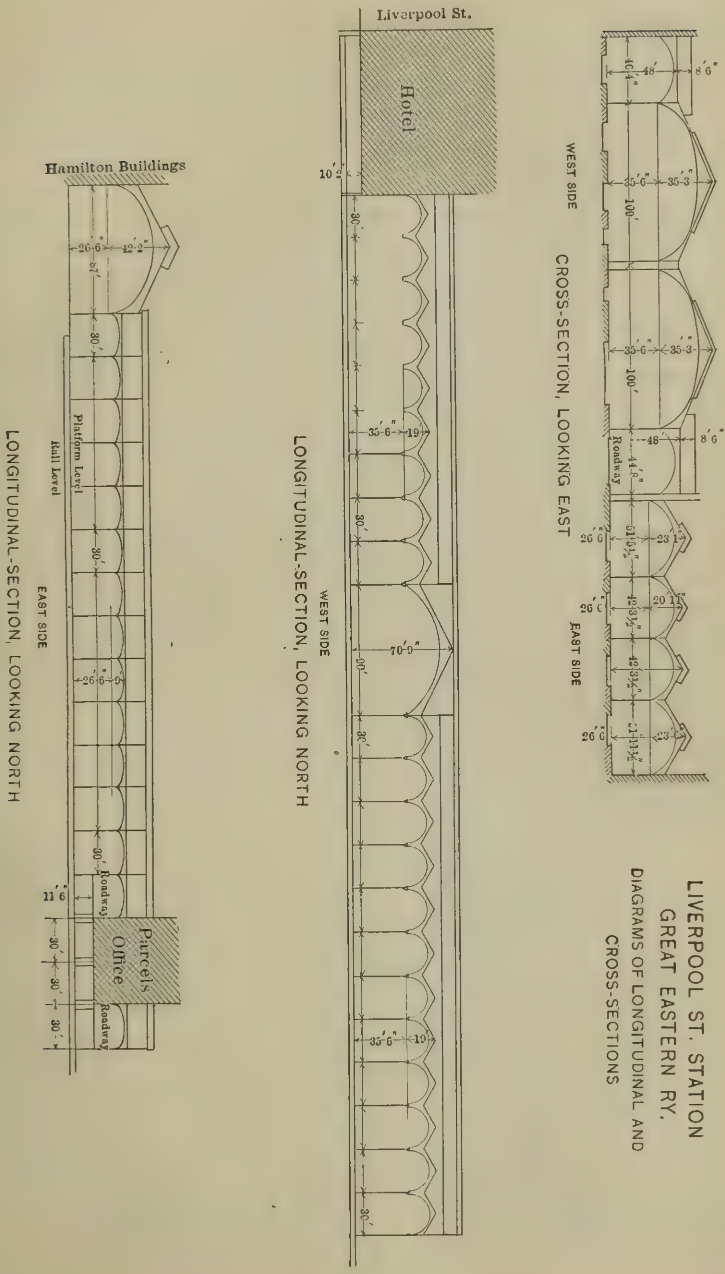
The company's hotel is situated between the cab entrances and exits, facing Liverpool Street, the back overlooking the main line platforms, with which it is connected by two stairways.

The building containing the main line booking offices, waiting-rooms, etc., on the ground floor, and the general offices of the company, on the upper floors, adjoins the hotel, and runs alongside the main departure platform for 250 ft., overlooking on the other side the main line cab approach. At the northern end of this building there is a wing extending westward along the circulating area at the end of the suburban platforms. At the extreme western end of this wing the suburban booking office is situated at street level. Refreshment and waiting-rooms, on the same floor as the booking hall, occupy the remainder of the building, access to the platforms being obtained by a footbridge with five stairways leading down to platform level.

There are eight platforms on the eastern side. They are about 20 ft. wide and 490 ft. long, and have an area of 65 425 sq. ft. The roofing over them consists of four spans of 49 ft. 7 in., 42 ft. 3½ in., 42 ft. 3½ in. and 51 ft. 7 in., respectively. (See section on Fig. 14.) The roof principals are of the lattice type, with elliptic, arched bottom booms, and are supported by cast-iron columns, 35 ft. 6 in. in height. The columns are spaced 30 ft. apart, down the middle of the platforms, and are connected by plate girders built to a segmental arch. The circulating area, which forms the southern end of the platforms, is covered by a roof of 88 ft. span, running at right angles to the platform roof, and having an area of 21 730 sq. ft.

About 1 235 tons of wrought iron and 340 tons of cast iron were used in the construction of this roof.

The approach to this portion of the station is from Bishopsgate



LONGITUDINAL-SECTION, LOOKING NORTH

LONGITUDINAL-SECTION, LOOKING NORTH

CROSS-SECTION, LOOKING EAST

LIVERPOOL ST. STATION
GREAT EASTERN RY.
DIAGRAMS OF LONGITUDINAL AND
CROSS-SECTIONS

Fig. 14.

Street Without, and consists of a covered cab road, running along the southern side of the booking hall at street level, or about 17 ft. above the level of the platforms. The passenger, on passing through the hall, finds himself on the footbridge, running across the whole station from east to west, which communicates with the platforms by three stairways.

Underneath the circulating area are the necessary conveniences for passengers, and offices for the staff. On the south side of the main entrance is an inclined road coming up from platform level to Bishopsgate Street Without, forming the cab exit.

The parcels office consists of a three-story brick building carried across the rails and platforms of the eastern half of the station by girders supported on cast-iron columns arranged in pairs. Access to the main line platforms on the west side is given by a gallery extended across the rails and connected with the platforms by 15-cwt. direct-acting hydraulic hoists. The parcels office is divided into an "Inward" and "Outward," with separate entrances to each from the public street, as shown on the plan. Two of the lifts are arranged to serve a subway below the passenger platforms, which allows of a duplicate means of conveying parcels from one platform to another. Above the parcels office are general offices belonging to the company, which are served by hydraulic hoists working upward from street level. The passenger platforms are equipped with hydraulic cranes to deal with bulky or heavy parcels arriving by passenger train. About 4 000 000 parcels are dealt with at this station in the course of a year.

The station is controlled by two signal boxes, known as the East and West Boxes, respectively. (See Signal Plan on Plate LIII.) The West Box has the master control of all trains admitted on the through, local and suburban lines, so that the signalman in the East Box cannot open any platform to an incoming train, nor start an outgoing one, without the permission of the operator in the West Box. The control between the two boxes consists of a bolt-locking and disengaging apparatus. There are 240 levers, in two sections of 120 each, fixed back to back in the West Box, and a frame of 136 levers in the East Box. In addition to these two boxes, there are also two small boxes which control the occupation of platforms. These boxes are connected electrically with the West Box, and

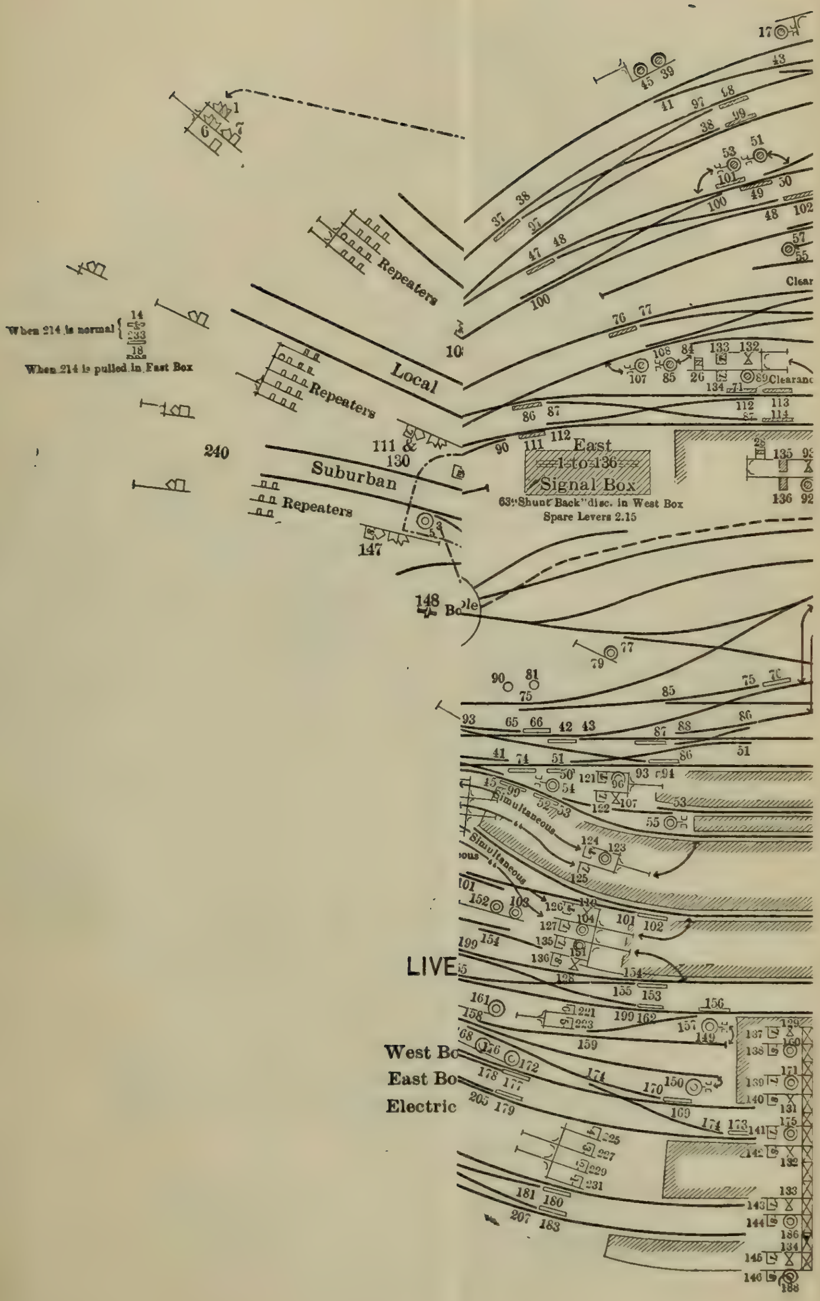
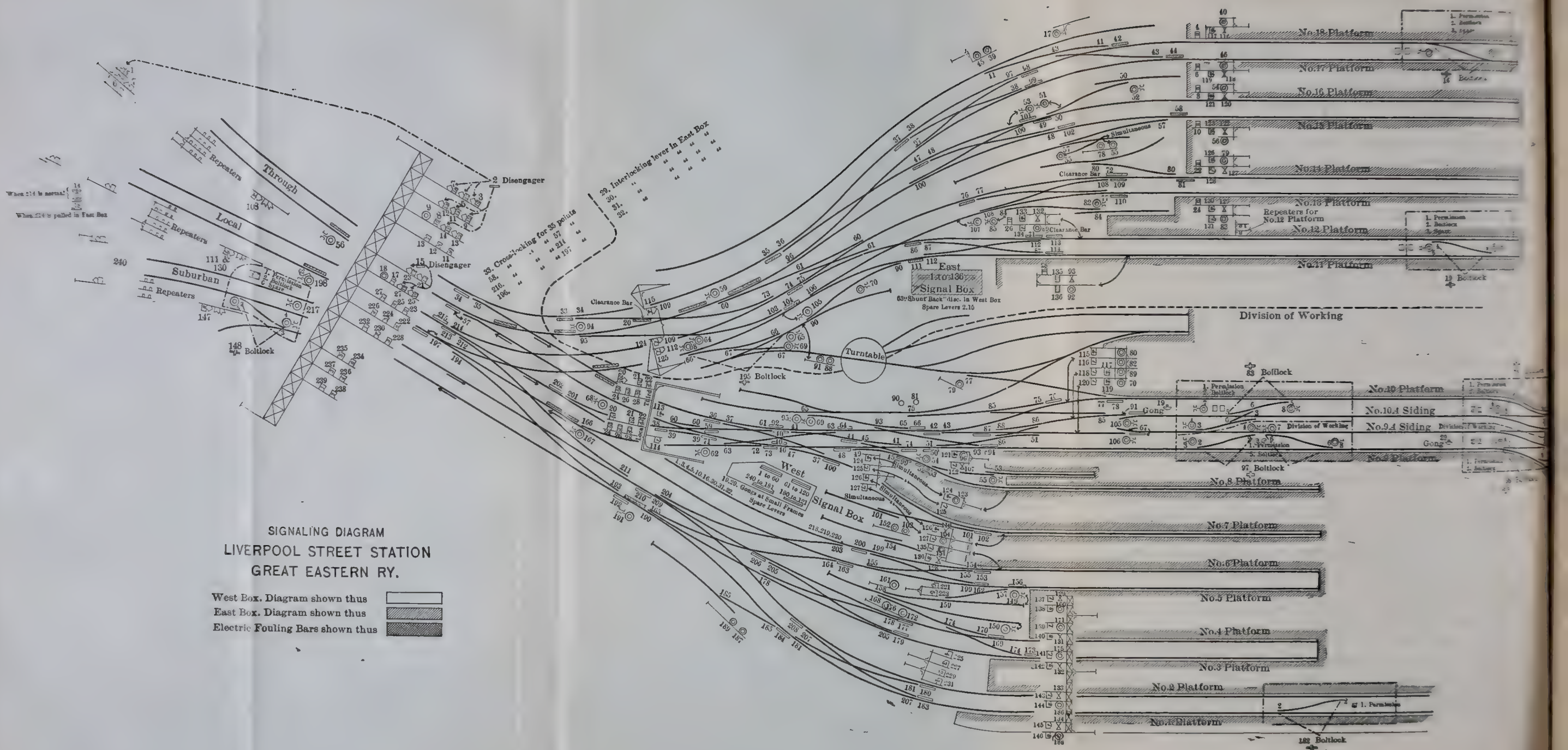

When 214 is normal
14
233
18
When 214 is pulled in East Box
240
Repeaters
Local
Repeaters
Suburban
Repeaters
111 &
130
147
148
Bo
East
1 to 136
Signal Box
63 "Shunt Back" disc. in West Box
Spare Levers 2.15
Clear
Clearanc
Simultaneous
Simultaneous
LIVE
West Bo
East Bo
Electric

PLATE LIII. VOL.
TRANS. AM. SOC.
INTER. ENG. CONG.
[illegible]
BRITISH RAILROAD TERMINALS



SIGNALING DIAGRAM
LIVERPOOL STREET STATION
GREAT EASTERN RY.

West Box. Diagram shown thus	☐
East Box. Diagram shown thus	▨
Electric Fouling Bars shown thus	■

their duty is to signal to the operator in the West Box which platforms are empty, Sykes's lock and block electrical signalling being used throughout. The failing of points is detected electrically. There are four signal arms to each platform, indicating shunting, local and suburban lines, according to the line on which the train should proceed. The fourth arm refers to engines moving into engine docks. The main home signals are carried on a light girder bridge at the end of the station, but, as they are not visible at a distance, they are repeated farther down the line, so that drivers may know what to expect when they arrive in view of them.

Owing to the lack of siding accommodation for empty coaches, trains have to be made up at Stratford, about 3 miles from the terminus, and run empty into the station, which, of course, increases the difficulty of working the traffic.

Some idea of the enormous amount of traffic dealt with at this station may be gathered from the fact that the total number of passenger trains passing in and out of the station in 24 hours is 822. This does not include 229 trains marshalled at Stratford and sent up empty to Liverpool Street, which would bring the total up to 1 051, nor 23 light engines which also pass in and out during the day. The busiest hours are from 7 to 10 A. M. and from 5 to 8 P. M. During these intervals, between 160 and 170 trains, nearly all of which are for suburban and local traffic, arrive and leave again. There is also a nightly service of 18 trains in and out between Liverpool Street and the suburbs. The average number of passengers using Liverpool Street Station during the 24 hours is about 200 000, and the total number in the course of a year is between 55 000 000 and 56 000 000, or nearly as many as are now dealt with at the forty-four stations on the Metropolitan District Railway.

The Bank Terminus. Central London Railway.—The Central London Railway, which passes along probably one of the finest passenger routes in the world, is, as is well known, an underground electric railway of about 6 miles in length, extending from Shepherd's Bush, in the west, to the City, in the east, as shown in dotted lines upon the map of London, Fig. 12. It consists of an up and a down line, carried in tubes, 11 ft. 8 in. in diameter. At stations, each of these tunnels emerges into one, 21 ft. in diameter, in which are provided the platforms, hoists, and stairways communicating with the booking offices at street level.

Owing to the enormous cost of land in the City, it was decided to construct the terminal station at the Bank wholly underground, the site selected being at the confluence of the streets fronting the Bank of England and the Mansion House.

It is not proposed to enter into any detailed account of the methods adopted for carrying out this exceedingly difficult portion of the work, which had to be executed without any interference with the enormous street traffic or with any of the adjoining buildings, including the Bank of England, for all this is described better in a paper before the Congress by the engineers who were responsible for the work. However, it is thought that a short description of the arrangements at this terminus, following upon the account just given of Liverpool Street Station, would be of interest, and afford a comparison between the terminal requirements of a line worked by steam, with ordinary long-distance and short-distance traffic, and one operated wholly by electricity, with trains at frequent intervals, for a purely omnibus traffic.

A general plan of the booking hall, subway, and approaches is given in Fig. 15. The stairways leading down from the principal streets are seven in number, and communicate with a subway which encircles the booking hall, 10 ft. 6 in. below street level. Three sets of stairways lead from this subway down to the hall, which is 6 ft. lower, or 16 ft. 6 in. below the surface. Two are reserved for entrance, and one for exit. Communication with the platforms, which are about 60 ft. below street level, is obtained by six shafts, five being furnished with electric lifts, and the remaining one containing a spiral stairway. There are five lifts, each having a carrying capacity of 80 persons. Each lift has two openings, one at each end, communicating at the booking hall level with the entrances and exits, and at the platform level with the arrival and departure platforms, respectively. In this way the streams of passengers never cross, the arrangements in this and other respects being perfect. The platforms are two in number, for arrival and departure, each being 325 ft. long by 11 ft. wide, carried on concrete arching. The lines are arranged so as to enable the shunting of a train to be accomplished in a little less than 2 minutes. (See Fig. 15, which shows the method of construction very clearly.)

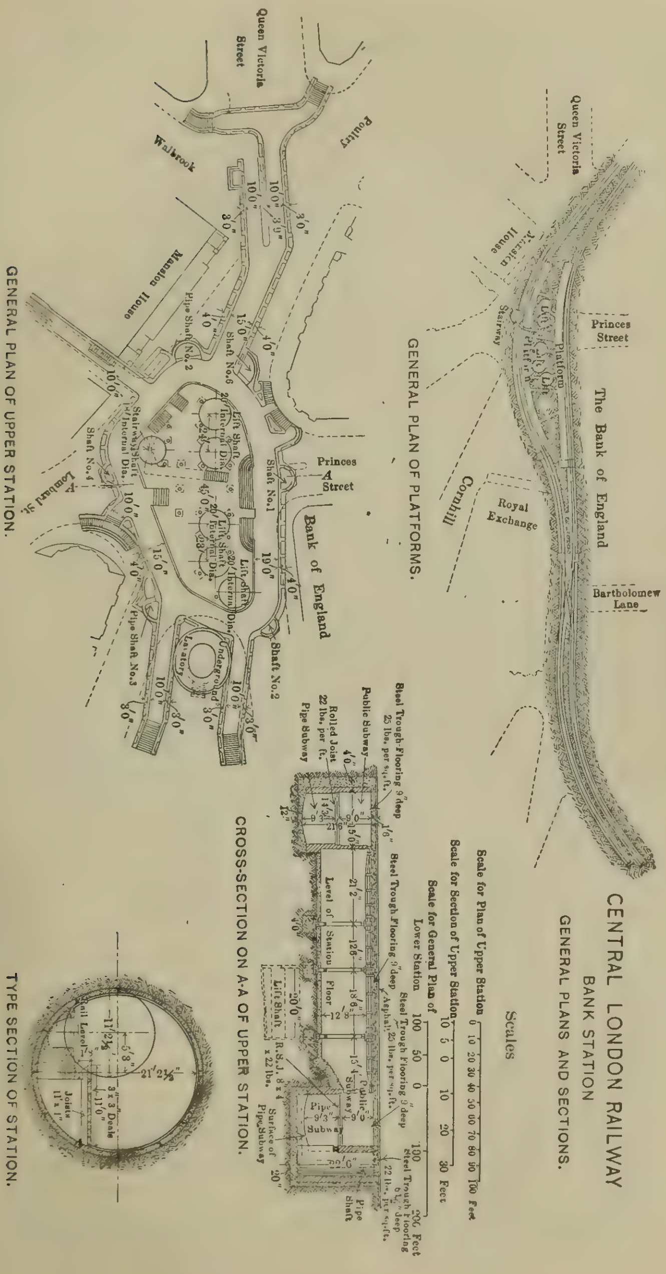

CENTRAL LONDON RAILWAY
BANK STATION
GENERAL PLANS AND SECTIONS.
Scales
Scale for Plan of Upper Station 0 10 20 30 40 50 60 70 80 90 100 Feet
Scale for Section of Upper Station 10 5 0 10 20 30 Feet
Scale for General Plan of Lower Station 100 50 0 100 200 Feet
GENERAL PLAN OF PLATFORMS.
Queen Victoria Street
Mansion House
Stairway
Lift
Platform
Princes Street
The Bank of England
Cornhill
Royal Exchange
Bartholomew Lane
GENERAL PLAN OF UPPER STATION.
Queen Victoria Street
Poultry
Walbrook
Mansion House
Pipe Shaft No. 2
Shaft No. 6
Lift Shaft 20' Internal Dia.
Stairway Shaft 24' Internal Dia.
Shaft No. 4
Lombard St.
Princes Street
A
Shaft No. 1
Bank of England
Lift Shaft 20' Internal Dia.
Shaft No. 2
Pipe Shaft No. 3
Lavatory
Underground
10'0"
3'0"
3'9"
4'0"
15'0"
19'0"
45'0"
CROSS-SECTION ON A-A OF UPPER STATION.
Steel Trough Flooring 9" deep 25 lbs. per sq. ft.
Public Subway
Rolled Joist 22 lbs. per ft.
Pipe Subway
Steel Trough Flooring 9" deep Asphalt 25 lbs. per sq. ft.
Level of Station Floor
Lift Shaft
R.S.J. 8 x 4 x 22 lbs.
Surface of Pipe Subway
Public Subway
Pipe Subway
Steel Trough Flooring 6¼" deep 22 lbs. per sq. ft.
Pipe Shaft
21'6"
21'2"
12'6"
18'6"
12'8"
15'4"
20'0"
22'0"
9'3"
9'0"
TYPE SECTION OF STATION.
Rail Level
11'2½"
21'2½"
11'0"
3 x 3 Deals
Joists 11' x 1"

FIG. 15.

The traffic is heaviest in the morning and evening, between the hours of 8 and 11 A. M. and 4 and 8 P. M. During these intervals there is a service of 27 or 28 trains per hour. The trains consist of seven coaches each, two of which are motor-coaches, placed at the ends of the train, the others being trailers. The former have each a seating capacity of 44 persons, and the latter of 48 persons, making a total of 328 per train. The carriages are of the corridor type, with gangways down the center and doors at each end.

The average number of trains per day in and out of the station is 336, and the number of passengers carried between 60 000 and 65 000, or about 22 000 000 per annum. The total length of platform provided for operating this very large traffic is 650 ft., having an area of 7 150 sq. ft.

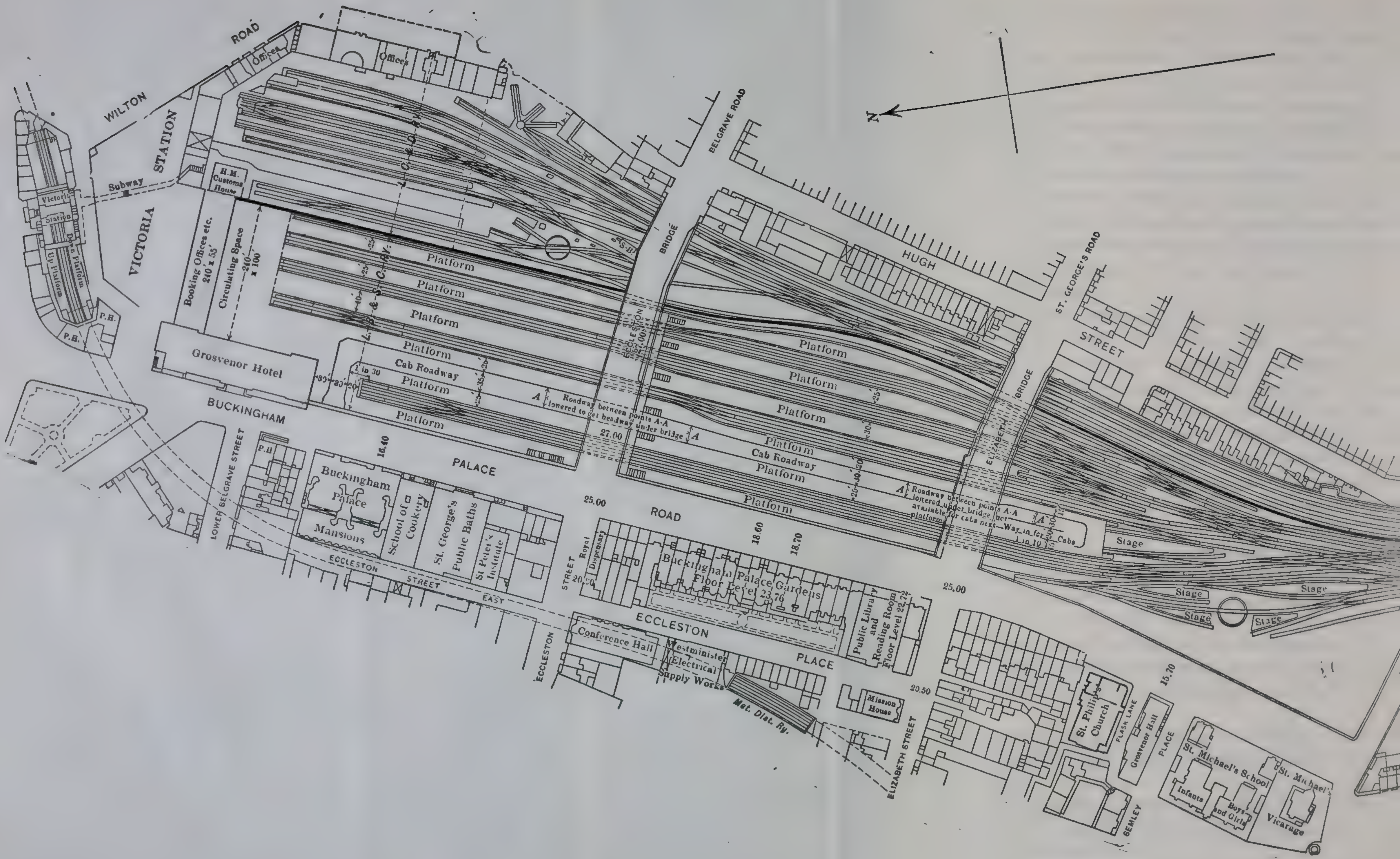
Victoria Station. London, Brighton and South Coast Railway.—To obtain the full benefit of the four lines of way to which the London, Brighton and South Coast Railway Company have augmented their main-track capacity, it has been found necessary to reconstruct and enlarge the terminus at Victoria, the works being still in progress. A plan of the new arrangements at this station is shown on Plate LIV. Five running lines will approach the station, developing into ten roads, and serving nine platform edges with accommodation for eighteen trains. The platforms, the widths of which are shown on the plan, will have a total length of 11 750 ft., or a little more than 2 miles. A circulating area, 240 by 100 ft., divides the platforms from the block forming the booking offices, waiting-rooms, etc., occupying an area of 13 200 sq. ft.

A cab road, 35 ft. in width, having an entrance from Elizabeth Bridge, which crosses the station at the southern end of the platforms, runs down the length of the station and has its exit in the Buckingham Palace Road at the southern end of the Grosvenor Hotel.

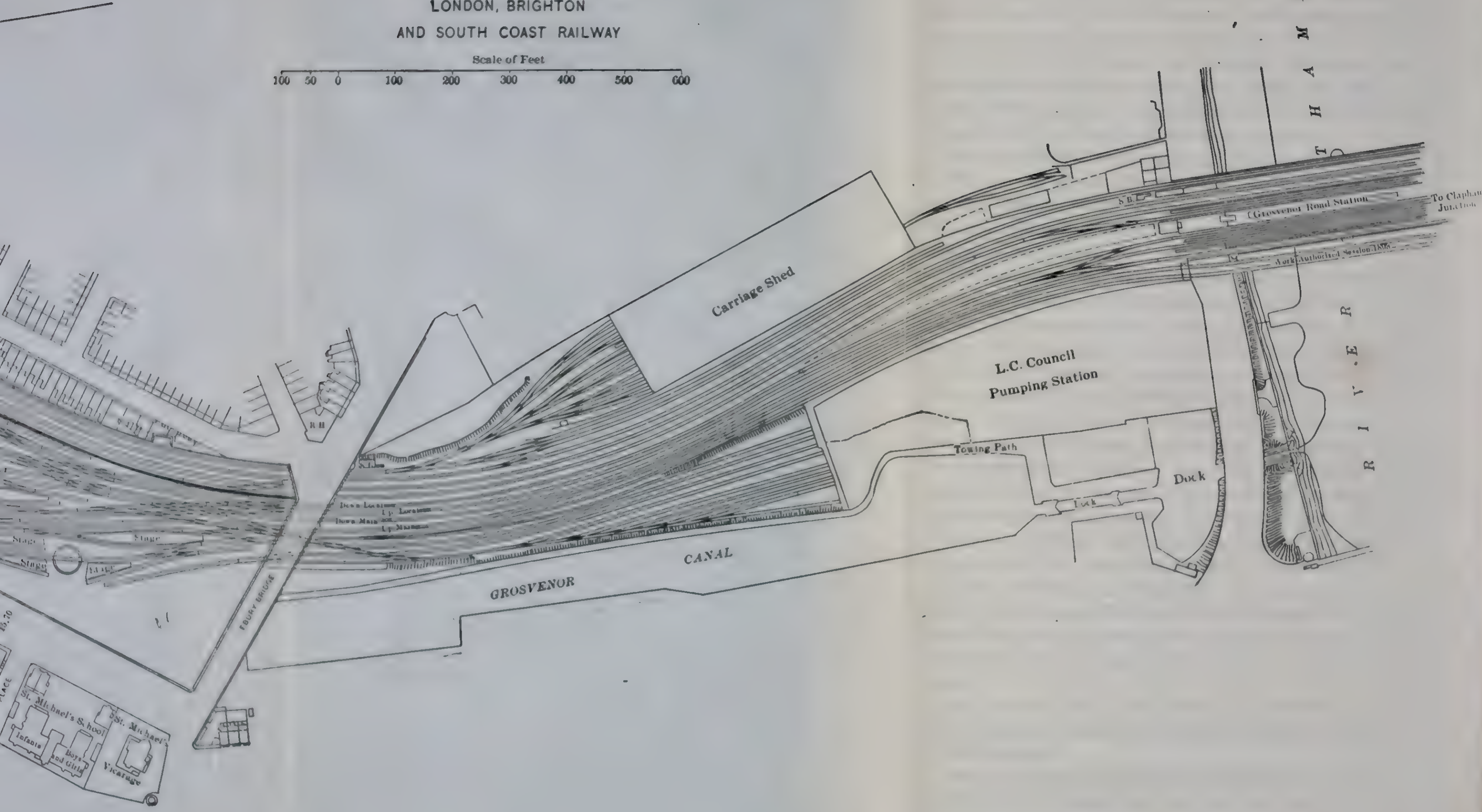
The platforms will be connected by a footbridge on the southern side of Eccleston Bridge, which crosses them at about the middle of their length.

South of Ebury Bridge additional sidings are to be laid, while, on the north side, stages are to be built for the purpose of dealing with horses, carriages, etc.

Sections of the roofing between the booking offices and Eccleston


N
WILTON
ROAD
Offices
Offices
STATION
VICTORIA
Subway
Victoria
Station
Down Platform
Up Platform
P.H.
P.H.
H.M. Customs House
Booking Offices etc. 240' x 55'
Circulating Space 240' x 100'
L. C. & D. R.
L. B. & S. C. Ry.
S. B.
Platform
Platform
Platform
Platform
Cab Roadway
Platform
Platform
Grosvenor Hotel
1 in 30
A
Roadway between points A-A lowered to get headway under bridge
A
27.00
27.00
BUCKINGHAM
PALACE
ROAD
18.40
BELGRAVE ROAD
BRIDGE
ECCLESTON
HUGH
ST. GEORGE'S ROAD
STREET
BRIDGE
ELIZABETH
Platform
Platform
Platform
Platform
Cab Roadway
Platform
Platform
A
Roadway between points A-A lowered under bridge, not available for cabs next platform
Way in for Cabs
1 in 10
A
Stage
Stage
Stage
Stage
Stage
25.00
25.00
25.00
LOWER BELGRAVE STREET
P.H.
Buckingham Palace Mansions
School of Cookery
St. George's Public Baths
St Peter's Institute
ECCLESTON
STREET
EAST
STREET
Royal Dispensary
20.50
Buckingham Palace Gardens Floor Level 23.76
18.60
18.70
Public Library and Reading Room Floor Level 22.72
ECCLESTON
PLACE
Conference Hall
Westminster Electrical Supply Works
Met. Dist. Ry.
ECCLESTON
Mission House
20.50
ELIZABETH STREET
St. Philip's Church
FLASK LANE
Grosvenor Hall
PLACE
15.70
SEMLEY
St. Michael's School
Infants
Boys and Girls
St. Michael's
Vicarage

PLAN OF
NEW STATION AT VICTORIA
LONDON, BRIGHTON
AND SOUTH COAST RAILWAY



ROOFING OF VICTORIA STATION L.B. & S.C. RY.
LONGITUDINAL SECTIONS THROUGH RIDGE AND VALLEY GUTTERS;
PURLIN DETAILS, ETC.

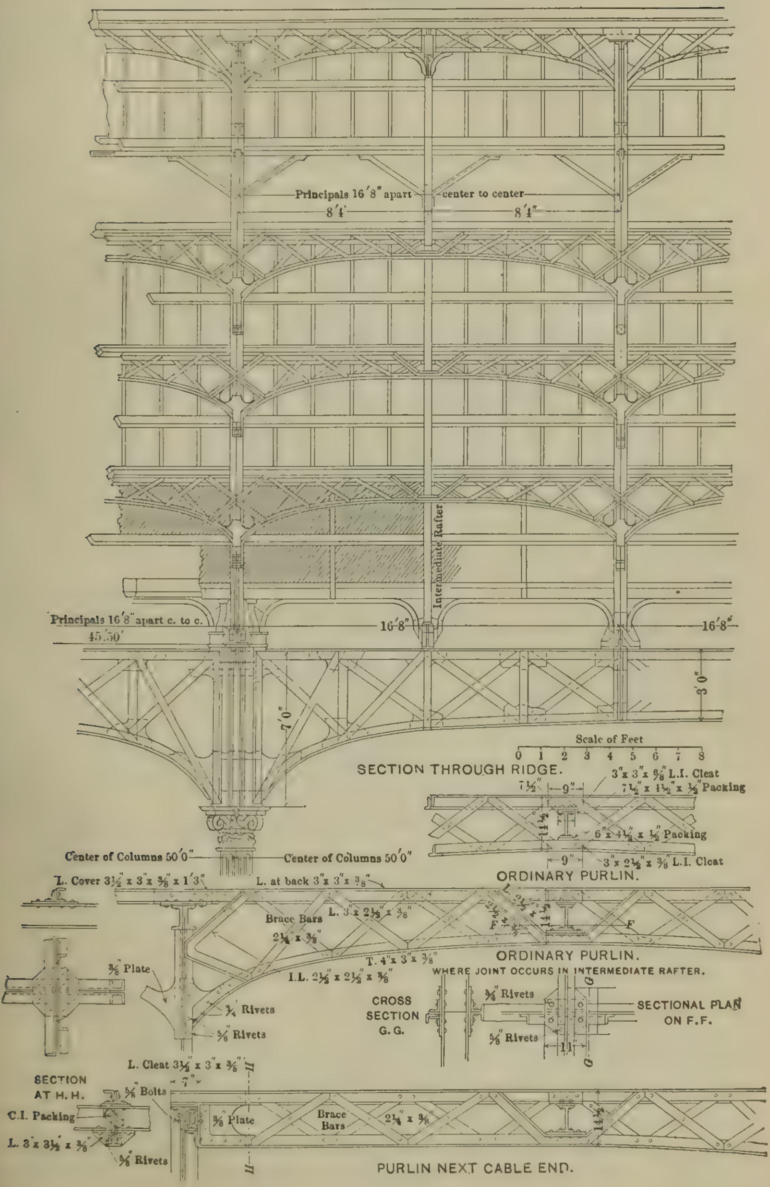


FIG. 16.

Bridge, and between Eccleston and Elizabeth Bridges are shown in Fig. 16 and Plate LV. From the longitudinal section, it will be seen that the principals are spaced at 16 ft. 8 in. centers, with an intermediate principal, and this arrangement is repeated throughout the whole roof.

The total area of the new station and yard will be 14½ acres, being an addition of 8 acres to the original site.

Between 550 and 600 trains run in and out of the station in 24 hours.

Waverley Station. North British Railway.—The entire remodelling of Waverley Station, Edinburgh, which took place between 1892 and 1899, was rendered necessary by the large increase of traffic consequent on the opening of the Forth Bridge in 1890. A plan of the new station is shown on Plate LVI, and Fig. 17 is a section of part of the roofing. From these it will be seen that it consists mainly of one large island platform pierced at either end by a number of bays to accommodate the local traffic which terminates at this station, and, as the local traffic forms more than 90% of the total dealt with, the station may be regarded properly as a terminal.

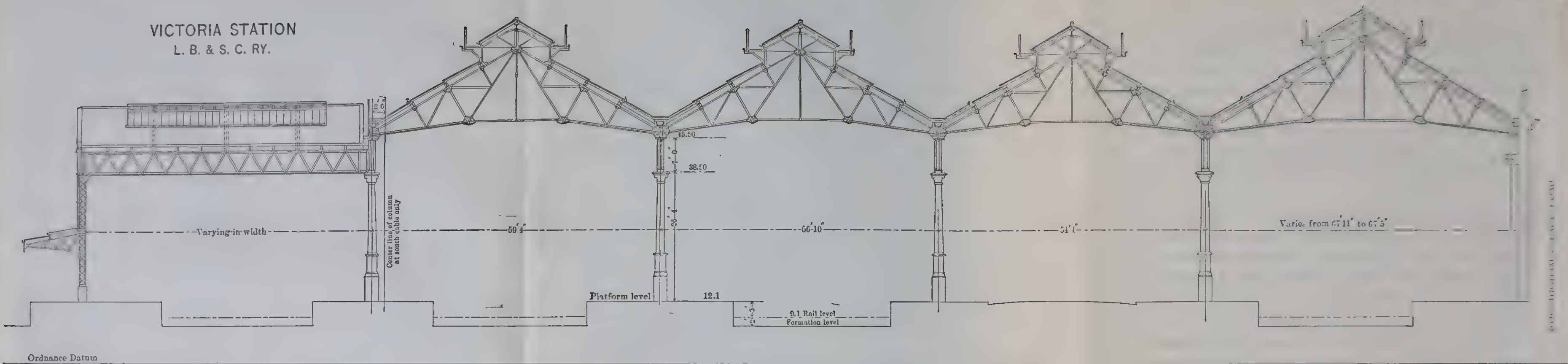
Four lines of way approach the station on the eastern side, pass under Calton Hill in two double-line tunnels, and leave it on the western side by one double-line and two single-line tunnels.

It will be seen from the plan that there are two main line platforms, each 1 680 ft. long, and fifteen terminal or dock platforms, the whole forming one large island between the main lines, in addition to which there is a smaller island platform serving two through suburban lines. The average length of the suburban platforms is 1 200 ft., and of the dock platforms 540 ft., the average width of all the platforms being 30 ft., and their total length 4 660 yd., or nearly 2¾ miles, giving an area of 32 520 sq. yd.

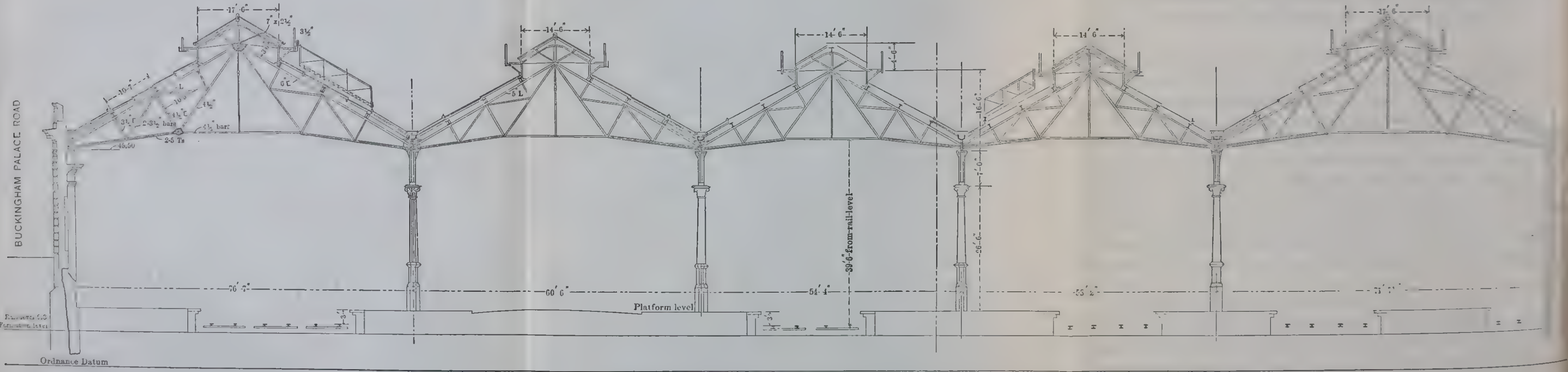
The station offices are conveniently situated in the center of the station, and partly under the arches of the North Bridge. They consist of a rectangular block of buildings three stories in height. The ground or platform floor is almost entirely taken up with the main hall, with the booking office at its center, the remainder of the block being occupied by waiting and refreshment-rooms, offices for the staff, and station master's residence.

PLATE LV. [illegible]
TRANS. AM. SOC. [illegible]
INTER. ENG. [illegible]
[illegible]
BRITISH [illegible]

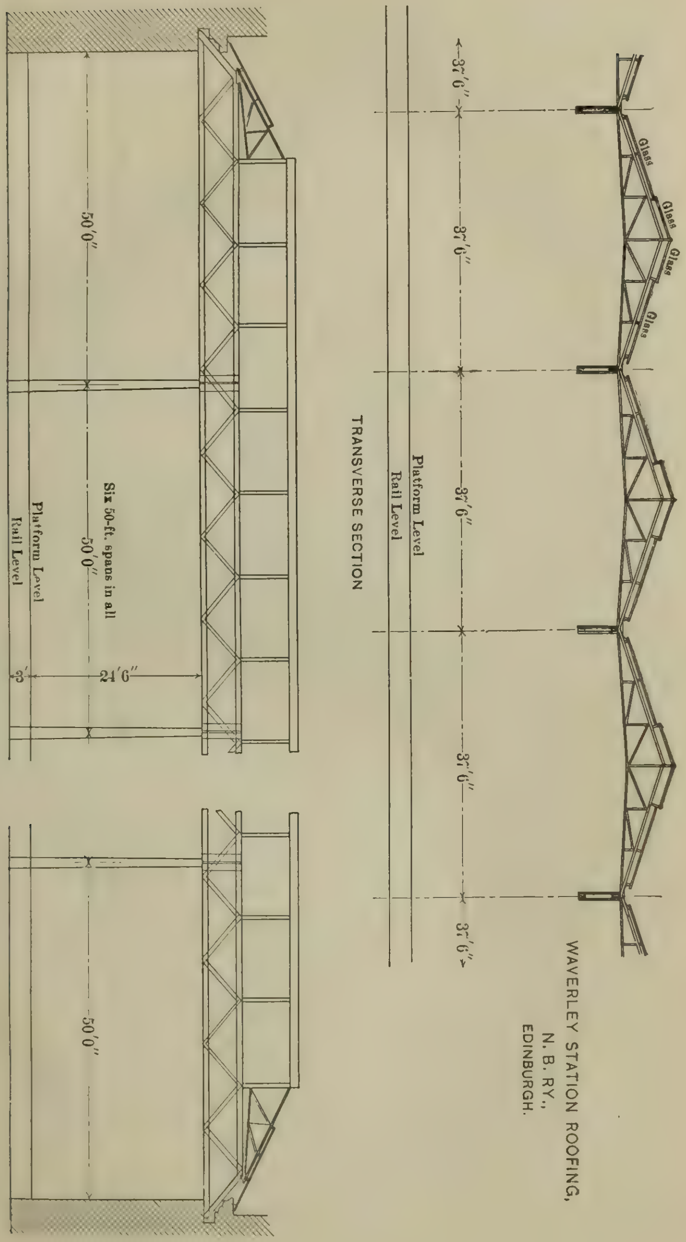
VICTORIA STATION
L. B. & S. C. RY.



CROSS-SECTION OF ROOFING BETWEEN ECCLESTON AND ELIZABETH BRIDGES



CROSS-SECTION OF ROOFING BETWEEN BOOKING OFFICES AND ECCLESTON BRIDGE



WAVERLEY STATION ROOFING, N. B. RY., EDINBURGH.

FIG. 17.

Cab access and exit are provided by a roadway from Waverley Bridge, which spans the station near its western end, the gradient to the roadway at platform level being 1 in 15, and there are, in addition, five footbridges, four of which give direct access to the platforms.

Between the tunnels under the "Mound," which forms its western, and New Street, which is its eastern boundary, Waverley Station occupies some 23 acres of ground, of which one-half is under roofing.

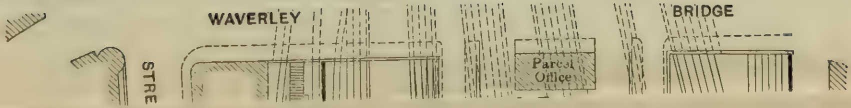
The main roof, sections of which are shown in Fig. 17, consists of 33 spans of 37 ft. 6 in. each, running at right angles to the station. The columns, which are placed in the middle of the platforms, support lattice girders, 6 ft. in depth, which carry the roof principals at intervals of 12 ft. The height of the roof is 42 ft. above the level of the rails, this being the maximum allowed by Act of Parliament, at the instance of the Edinburgh Corporation. In addition to the main roof, there is a verandah roof over the suburban and bay platforms, supported on a double row of columns.

The hydraulic power station is at Abbeyhill, about ¾ mile east of Waverley Station, and it supplies Leith Central Station in one direction and Haymarket Station in the other. The pumping engines are of the plain high-pressure horizontal type, giving a working pressure of 700 lb. per sq. in. in the mains.

The station is lighted throughout by electricity, the current being obtained at a comparatively low rate from the Edinburgh Corporation generating station. Both incandescent and arc lamps are used, the former at a pressure of 230 volts and the latter, which are of the Crompton type, of 7 and 10 amperes, at 460 volts.

The water supply of the station is obtained from the town mains through a 9-in. pipe discharging into a tank 100 ft. long, with a capacity of 75 000 gal. The tank is placed on the southern wall of the station, on the east side of North Bridge.

There are 228 points connecting the four lines with the various platforms and sidings, necessitating the use of 290 signals. The signals and points are controlled by two large signal cabins at either end of the station, and two smaller ones. The cabin at the east end of the station contains one of the largest frames in existence, having 260 levers. The signals are carried across the lines of way on bridges situated near the east and west cabins.


WAVERLEY
BRIDGE
Parcel Office
STRE

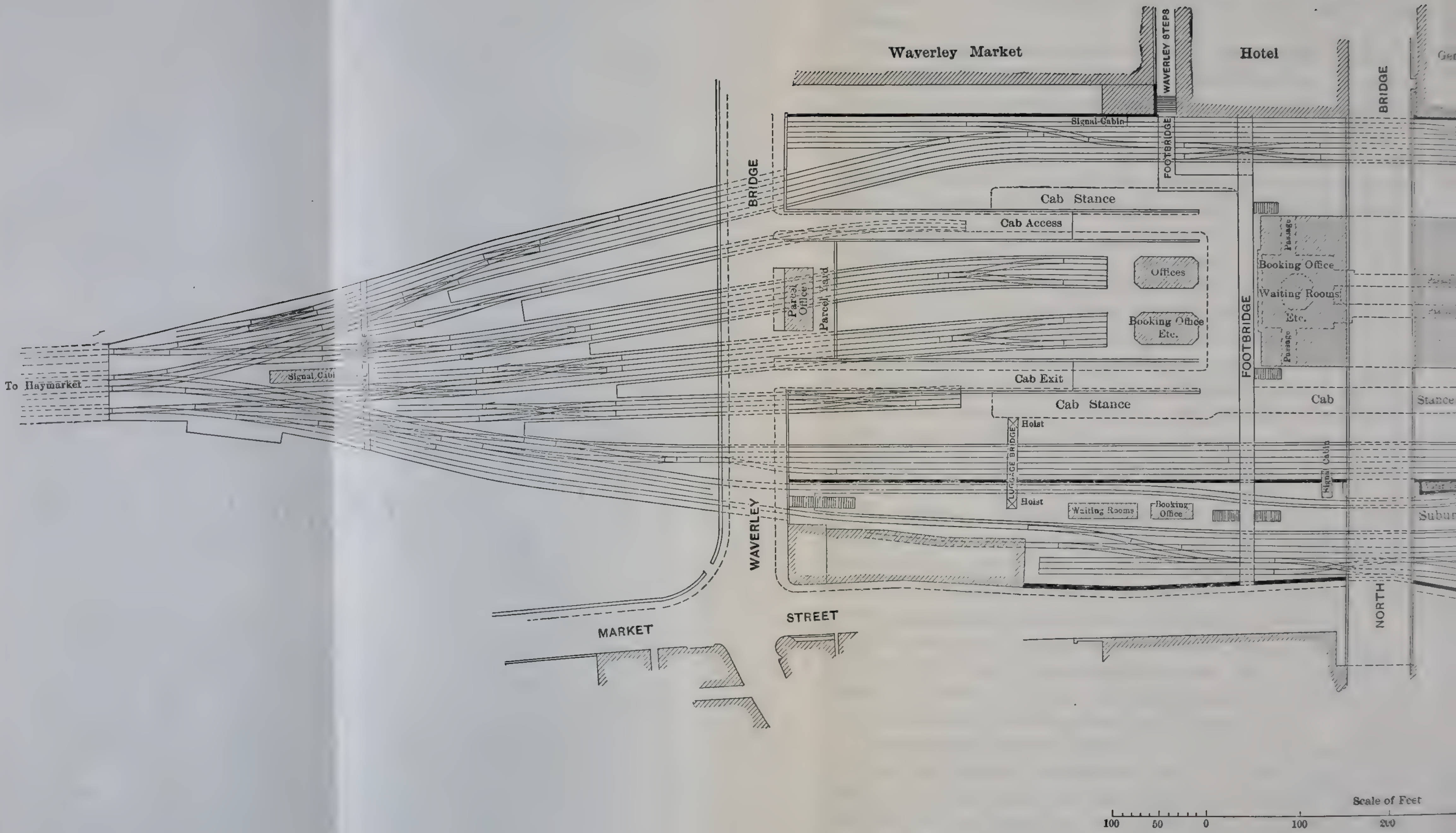
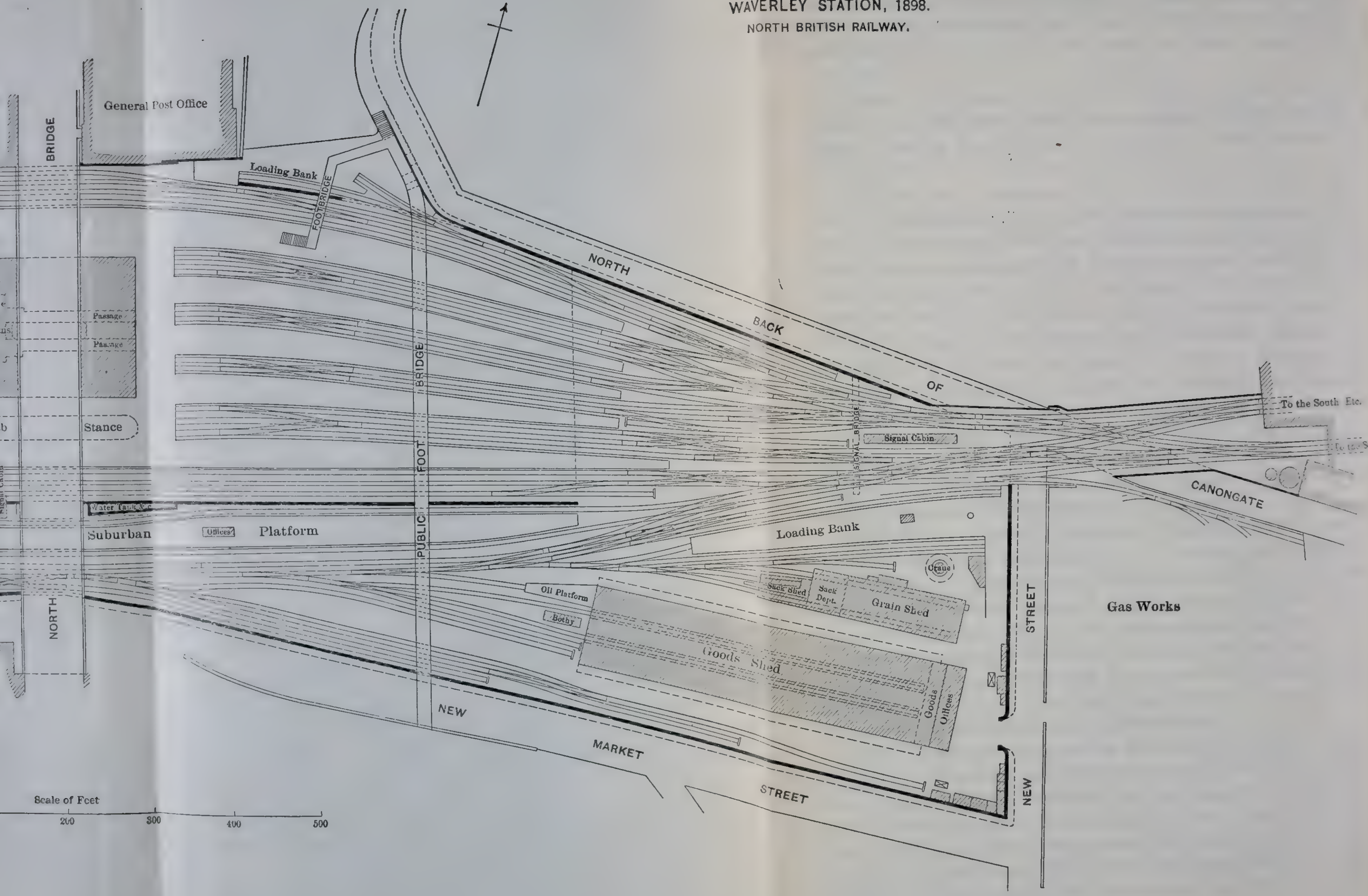

Waverley Market
WAVERLEY STEPS
Hotel
BRIDGE
Ge
Signal Cabin
FOOTBRIDGE
BRIDGE
Cab Stance
Cab Access
Offices
Booking Office
Waiting Rooms
Etc.
Passage
Passage
Booking Office
Etc.
Parcel Office
Parcel Yard
To Haymarket
Signal Cabi
FOOTBRIDGE
Cab Exit
Cab Stance
Cab
Stance
Hoist
LUGGAGE BRIDGE
Hoist
Waiting Rooms
Booking Office
Signal Cabin
Subur
WAVERLEY
MARKET
STREET
NORTH
Scale of Feet
100 50 0 100 200

PLATE LVI. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
FOXLEE ON
BRITISH RAILROAD TERMINALS.

WAVERLEY STATION, 1898.

NORTH BRITISH RAILWAY.



The goods station, which is southeast of the passenger station, is built almost entirely on brick arching of 30 ft. span. It contains a goods shed, about 430 ft. long by 90 ft. wide, in which there are three platforms equipped with hydraulic cranes having lifting capacities varying from 30 cwt. to 7 tons, and also with hydraulic hoists communicating with the arches below, which are used as vaults. To the north of the goods shed is a grain shed, which is also connected with the arching here used as grain stores by means of grain shoots and hydraulic hoists.

The total cost of the work, which included the reconstruction of two bridges and a road diversion, was about £1 500 000, of which £500 000 was expended on the station alone.

About 800 trains use the station in 24 hours, dealing with an average of 40 000 passengers per day, or nearly 15 000 000 per annum.

Paragon Station, Hull. North Eastern Railway.—This station is now in course of reconstruction, and the first half of the works will be completed in 1904. The station is entirely devoted to passenger traffic, plus the fish traffic conveyed by passenger trains. Both the main frontage and entrance are on Brook Street, with a cab approach passing along the south side from Anlaby Road.

The greater portion of the front is occupied by the Station Hotel, next to which is the booking hall, while the remainder is devoted to the station offices. The refreshment-rooms are on the ground floor of the hotel. On the south side, and parallel to the platforms, there are waiting-rooms and a parcels office, and on the opposite side there are other offices, emigrants' rooms, and a fish store. The booking hall leads to a circulating area, 300 ft. long by 90 ft. wide, running across the whole width of the station. The main platforms, nine in number, are at right angles to the circulating area. These vary from 600 to 800 ft. in length, and have a mean width of 30 ft. There are three additional short platforms for local traffic, varying from 260 to 365 ft. in length, and two excursion platforms about 770 ft. long.

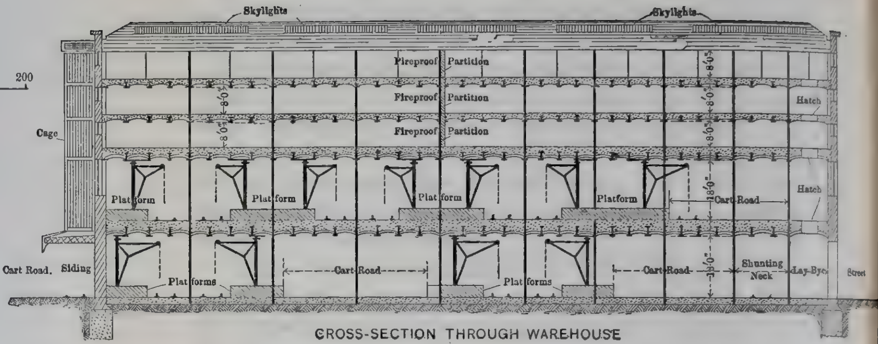
The roof will consist of five spans of varying widths, *viz.*, 64 ft. 5 in., 70 ft., 58 ft. 6 in., 64 ft. 9 in., and 64 ft. 3 in., respectively. The greater portion of the platforms, *i. e.*, as far as the end of the station offices on the south side, will be roofed in by these spans, while the remaining lengths are to be covered by verandah roofing carried on a double row of columns down each platform. The principals in the main roof will be segmental in form, spaced 10 ft. 2 in. apart, and the columns placed on the platforms at a distance of 37 ft. 7 in from center to center.

Park Street Bridge, which forms the western limit of the station, spans seven lines of way. Six of these are set apart for passenger traffic and serve the fourteen platforms of the station, and the remaining one divides into two branches, one running northward to a coal depot, the other connected with a set of nine sidings, three of which go into dock platforms in front of the fish store on the north side of the station.

Paragon Station accommodates the trains of four railway companies, *viz.,* the Great Central, the London and North Western, the Lancashire and Yorkshire, and the North Eastern Railways. The average number of trains, not including light engines and empties, is 207 in and out during 24 hours.

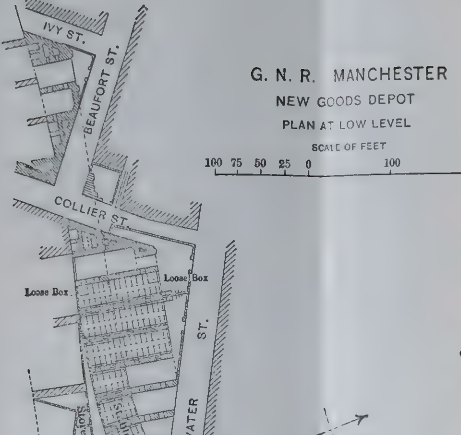
Deansgate Goods Depot, Manchester. Great Northern Railway.—Parliamentary powers were obtained for the construction of a short connecting line terminating in the new goods depot at Deansgate in 1895. The yard commences by a double junction with the Cheshire Lines (of which the Great Northern Company is a joint owner), at the end of Cornbrook Viaduct, about ½ mile from the station. From this point three lines of way are carried upon a viaduct as far as Bridgewater Street, where they fan out into twelve lines, ten of which are continued over the streets up to the warehouse. Six lines enter the building itself, which is at the northern end of the depot, the whole forming the high-level station.

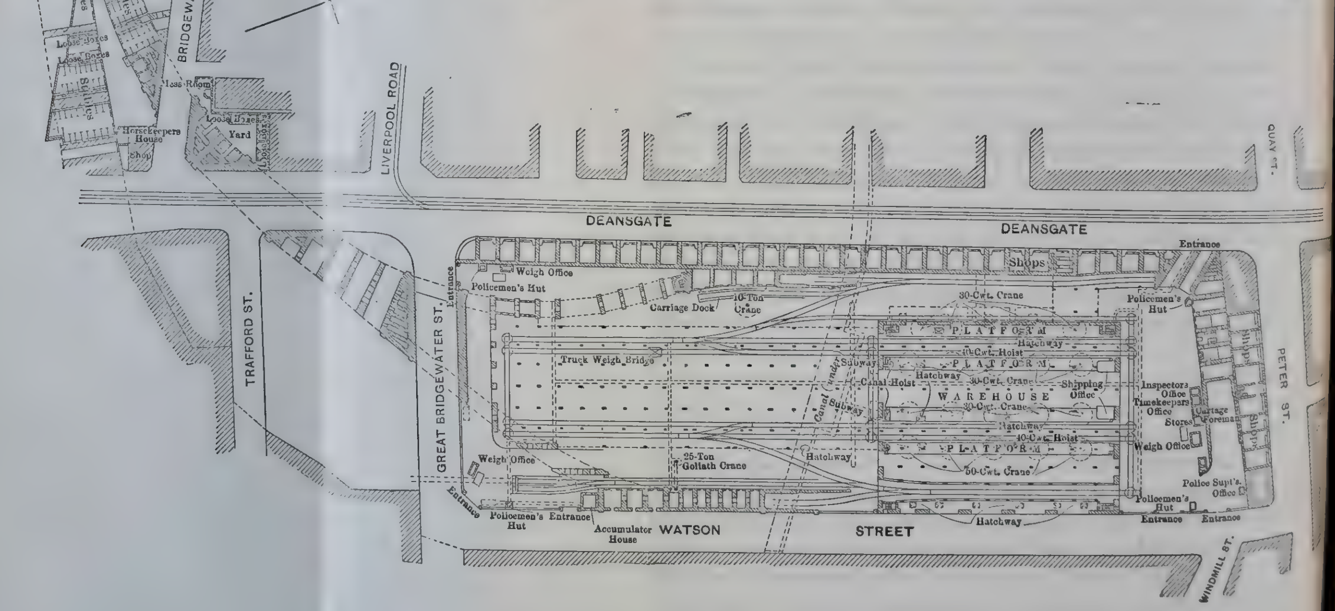
The remaining two lines are carried down, one on either side of the site, by inclines having a gradient of 1 in 28, to the street level, where they connect with sidings in the low-level yard, thus obviating the use of wagon hoists. Four of these lines also enter the warehouse, immediately under those just described on the high level, while a fifth is enclosed, and, passing through the warehouse, forms a shunting neck for the eastern incline. It will thus be seen that the arrangement which is shown on Plates LVII and LVIII constitutes a double-decked station. Convenient cart access is obtained on the high level by an inclined approach, carried upon arch-



CROSS-SECTION THROUGH WAREHOUSE

G. N. R. MANCHESTER
NEW GOODS DEPOT
PLAN AT LOW LEVEL





ing at the northern end, and to the low level by entrances at the four corners of the site. Further auxiliary access for carts and lorries to the warehouse is provided by the "lay-bye" on the Watson Street front.

The approach viaduct is of brick arching with steel girders and jack-arching over the streets, except in the case of Deansgate, where flat floor-plates are substituted. The high-level sidings are carried over the low-level yard on steel girders and stanchions, the floor being formed of jack-arching and concrete, rendered water-tight by asphalt. By this means the sidings in the center of the low-level yard are roofed over. The six lines that enter the warehouse on the high level serve platforms approached by a wide roadway which runs along the northern end and eastern side of the warehouse, and is connected with the surrounding streets by the sloping approach already referred to.

The four lines that enter the warehouse on the low level serve four platforms which run the entire length of the warehouse, ample cart access being provided, as shown on Plate LVII.

The warehouse, Fig. 18, which is fire-proof throughout, is built of brickwork in cement, the lower portions of pressed blue brick and the remainder of red brick relieved with blue bands. It is 267 ft. in length by 217 ft. wide, and is carried up to 75 ft. above street level. It has three storage floors above the upper, and a cool cellar below the lower set of rails. The whole of the floors consists of steel girders, jack-arching and concrete, supported upon built-up steel stanchions. Lines of tramway, with turn-tables at the intersections, are laid on the storage floors, for facilitating the handling of goods. The roadways and approaches outside the warehouse are paved with granite setts laid upon concrete, and those inside the warehouse, including the portion of the low-level yard under the approach viaduct, are paved with Australian hardwood.

Inside the warehouse on the high level there are twenty-five Armstrong 30-cwt. cranes and on the low level fifteen 30-cwt. and five 50-cwt. cranes. Two hydraulic hoists are provided to work from the platforms on the low level to the topmost floor of the building. There are also ten jiggers for handling goods from the trucks and lorries to the warehouse. In the yard outside there is one 25-ton crane, another with a capacity of 10 tons, and two hand-cranes of 6 tons each. Cart and truck weighbridges are also put down in convenient positions. Hydraulic capstans are provided on both levels for the purpose of facilitating the handling of railway wagons, and the arrangements on both the high and low levels are such as to enable a large and growing traffic to be dealt with expeditiously at a minimum cost.

The hydraulic power for the cranes, hoists, capstans, etc., is taken from the corporation mains. The buildings and yards are lighted throughout by electricity, supplied from the same source. Ample provision has been made against fire, the warehouse having been fitted with sprinklers. The storage floors have division walls, as shown, fitted with fire-proof doors which close automatically by an arrangement of fusible links.

A disused branch of the Bridgewater Canal passes in tunnel under the site, immediately in front of the warehouse, about 35 ft. below the lower set of rails, and is connected with the Manchester Ship Canal by means of the River Irwell. This old tunnel has been widened, the waterway dredged and driftways formed, and connected with the warehouse by hydraulic hoists, which serve all the floors.

The company's offices, which form a handsome block of buildings, are at the northern boundary of the depot, and are built over a range of shops facing Peter Street, adjoining the approach to the high level, the arches of which are utilised for the accommodation of the working staff. The valuable frontage next Deansgate has been similarly utilised for the erection of shops. Stabling for about 200 horses is provided in the arching of the approach viaduct in Bridgewater Street.

The contract was let in the latter part of 1896, the work of clearing the site began in February, 1897, and the construction in the spring of that year. The first half of the depot was opened on July 1st, 1898, and the work, in which about 50 000 tons of concrete, 25 000 000 bricks, 12 000 tons of mild steel, and 1 500 000 setts were used, was practically completed by the end of the following year.

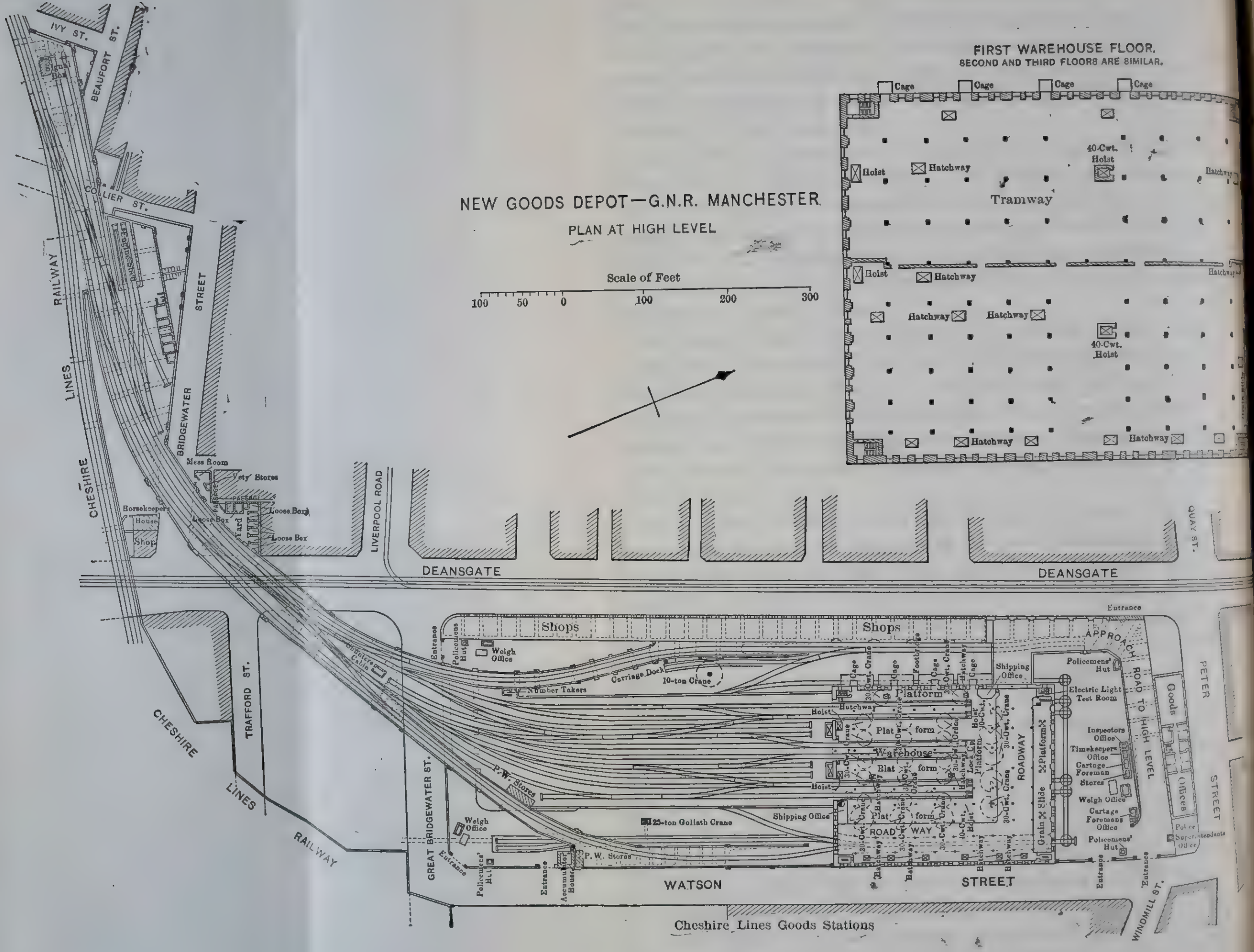
There is standing room for about 500 wagons on the two levels, and 33 880 sq. yd., or about 7 acres of storage space in the warehouse.

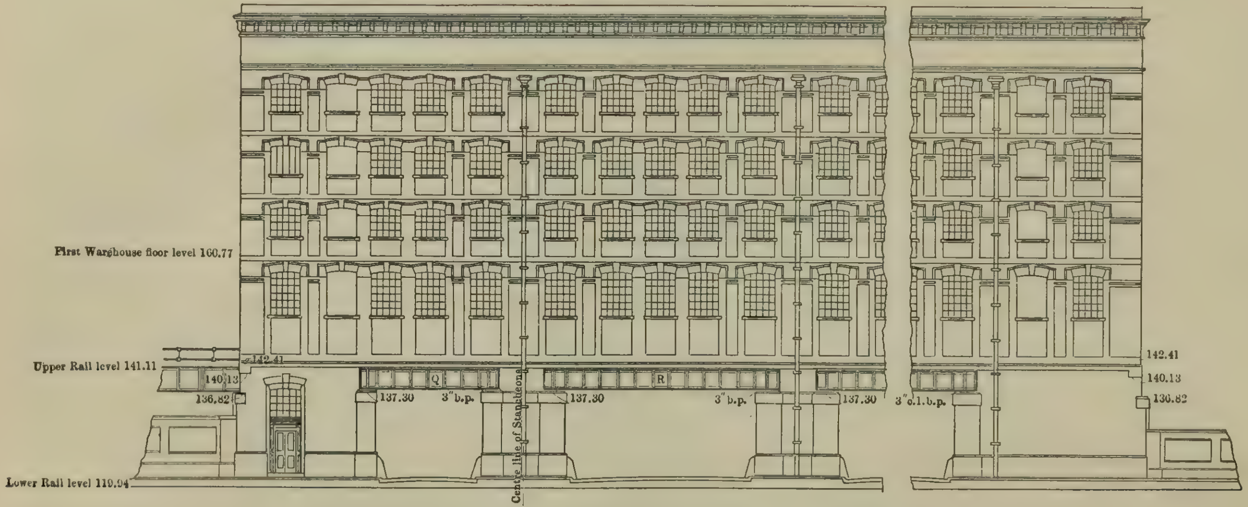
Aston Goods Depot. Birmingham. London and North Western Railway.—The London and North Western Railway Company's new

PLATE LVIII. VOL. LIV. PA
TRANS. AM. SOC. CIV. ENG
INTER. ENG. CONG., 190
FOXLEE ON
BRITISH RAILROAD TERMIN

NEW GOODS DEPOT—G.N.R. MANCHESTER.

PLAN AT HIGH LEVEL





GREAT NORTHERN RAILWAY COMPANY'S NEW GOODS WAREHOUSE AT MANCHESTER

ELEVATION TOWARD WATSON STREET

Scale of Feet
0 2 4 6 8 10 20 30 40

FIG. 18.

goods station at Aston, near Birmingham, was opened for traffic in 1901, the total area of the yard being 12½ acres. Although the new depot is a comparatively small one, the arrangements, a plan of which is shown on Plate LIX, are those most recently adopted by one of the leading railway companies in England, and, therefore, a description of them may be acceptable. Two lines of way approach the yard from Aston, which, on entering it, fan out into nineteen sidings. Of these, six enter the warehouse in pairs, and two run alongside the covered cart roads on each side of it, so that direct loading from truck to cart or *vice versa* can take place, and the remainder serve as standing and marshalling sidings.

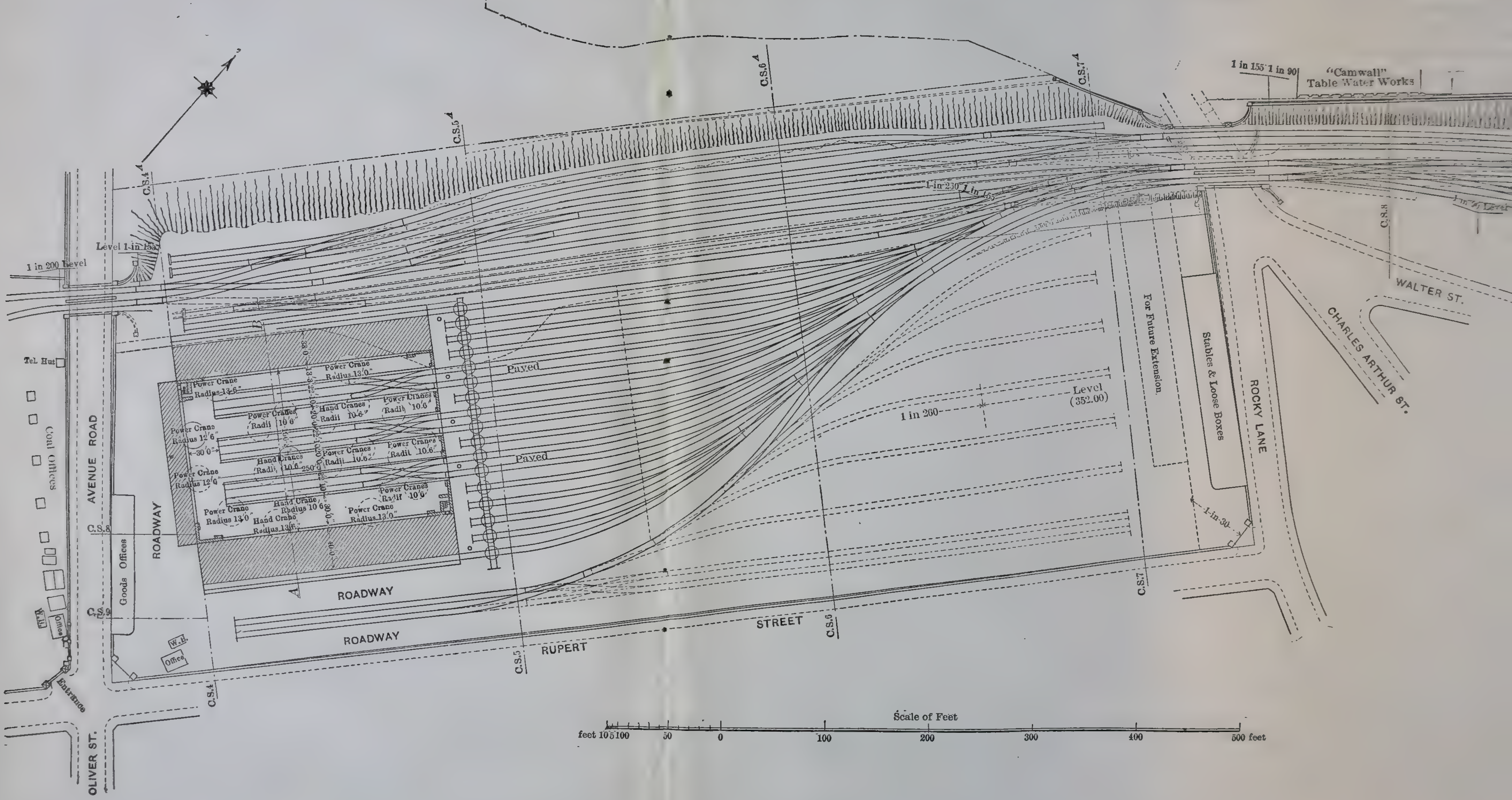
The warehouse, a section of which is also shown on Plate LIX, is a three-story building, 250 ft. long by 156 ft. 3 in. wide, with a large dry basement, which is used for goods requiring cool storing. The ground floor is used for handling goods, and the two upper floors for warehousing. On the former, a platform, 30 ft. wide, runs along the front and east of the building, while down the west side it is narrowed to 13 ft. 3 in. Two platforms, 20 ft. wide, also run down the middle of the building, thus dividing it into three bays, each 22 ft. 10 in. wide, into which the six sidings mentioned above run in pairs. The special point about this warehouse is that on the east, west and front or south sides, the walls of the stories above are carried by steel girders supported on columns, thereby doing away with doors and enabling drays to back up to the platforms at almost any point. The total number of drays for which there is room is 60, *viz.,* 14 on the front and 23 on each side. The roadways on the three open sides are roofed in, so that operations are carried on under cover.

To facilitate the handling of goods, 24 cranes, of 30 cwt. lifting capacity, have been arranged in convenient positions on the platforms. The two floors above have an area of 37 500 sq. ft. and a clear headroom of 8 ft. They are divided down the middle by a brick wall, the openings of which are closed by fire-proof doors.

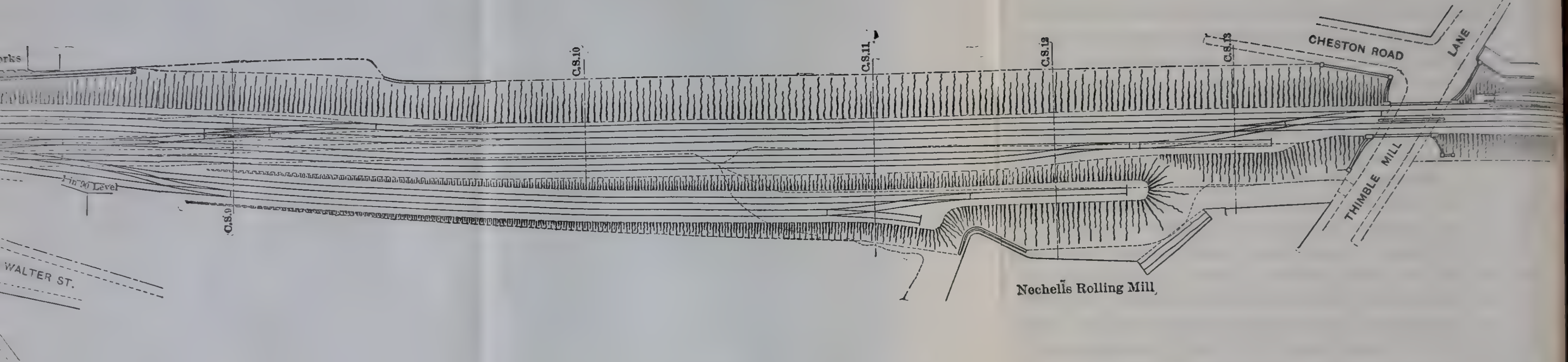
Two lifts, in addition to 15 hydraulic jiggers, connect the upper floors with the ground floor. For removing goods to or from drays direct, six hoists, three on each side, pass through the roof over the roadways and communicate with the warehouse floors. Four grain shoots are also provided, resting at an angle of 20 degrees. The

PROPOSED ADDITIONAL GOODS WAREHOUSE, OFFICES, STABLES ETC., ASTON, BIRMINGHAM.

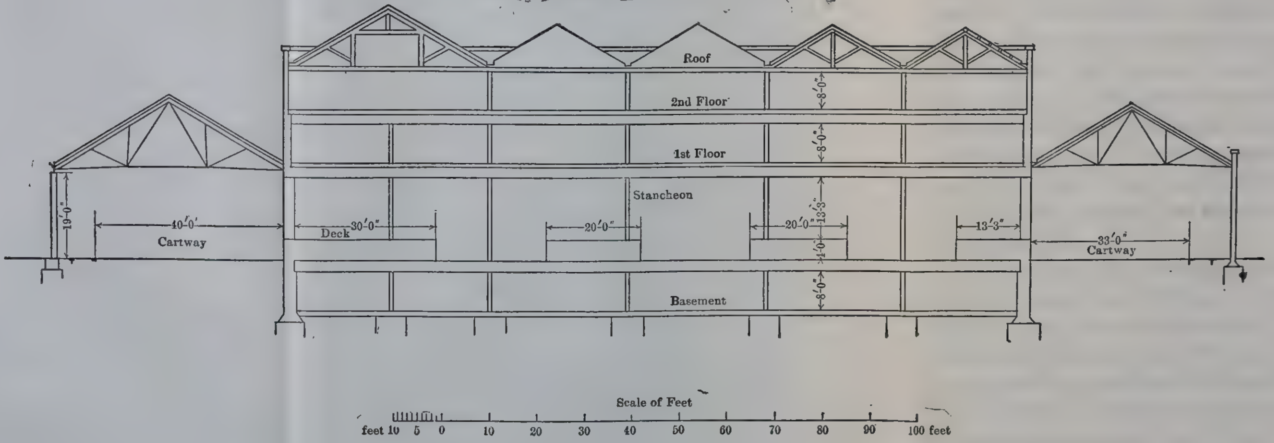
FOR THE LONDON & NORTH WESTERN RY.



IRMINGHAM.



SECTION THROUGH WAREHOUSE ON A.B.



shoots are fitted with automatic tumblers at their lower ends, on which the sacks are deposited on their way to the drays. Speaking tubes are also fitted to all floors.

The arrangements for the prevention of fire are very complete. Hose and nozzles are distributed in convenient places, water is supplied from the town mains, and a supplementary supply in case of accident is obtained from a water-tower erected by the company. Sprinklers are fitted throughout both the warehouse floors and in the basement. In the open, as can be seen from the plan, there are two pairs of sidings, approached by a roadway, for dealing with station-to-station traffic. There is also a carriage landing and ramp for handling furniture vans, carriages, etc. It will be noticed that there are fourteen turn-tables on the lines leading to the shed. These had to be put down, owing to there being insufficient space for points and crossings. The turn-tables are placed about 60 ft. from the warehouse. Six capstans and twenty-four dummies are provided in connection with these. The stables, which accommodate 103 horses, occupy a portion of the yard, and have a separate entrance from the street.

The public entrance to the yard is at the south corner, and near it there is a weighbridge and office. The main goods offices are in front of the warehouse, overlooking Avenue Road.

Blackpool Stations. Lancashire and Yorkshire Railway.—The Central and Talbot Road Stations, constructed and maintained by the Lancashire and Yorkshire Railway Company on behalf of that company and of the London and North Western Company, in this extremely popular northern seaside resort, furnish excellent examples of the arrangements required for working an enormous excursion traffic. The lines constitute a double track up to a distance of about ¾ mile from the stations; they then resolve themselves into four lines of way, with loops to sidings for the accommodation of a large number of empty trains. This standing room has been provided conveniently near both termini. At the Central Station there are 6½ miles of these sidings, and at Talbot Road about 4½ miles.

The Central Station consists of fourteen platforms in all, of which six are used for the ordinary traffic and the remainder for excursion traffic. The ordinary platforms have an average length of 200 yd., their total length being 1 230 yd. The excursion platforms vary from 180 to 217 yd. in length, with a total of 1 613 yd.

At Talbot Road there are fifteen platforms, six for ordinary and nine for excursion traffic. The latter vary between 207 and 253 yd. in length, yielding a total of 2 029 yd.; the former, as in the case of the Central Station, have an average length of 200 yd., amounting altogether to a total of 1 230 yd.

The number of trains that ran in and out of Blackpool (Talbot Road) on a bank holiday, August 3d, 1903, and in and out of Blackpool (Central) Station on Saturday, August 15th, 1903, two of the busiest days of last season, were as follows:

BLACKPOOL (TALBOT ROAD), MONDAY, AUGUST 3D, 1903.

	Arrivals.	Departures.	Total.
Ordinary trains	50	50	
Special trains	56	56	
	106	106	212

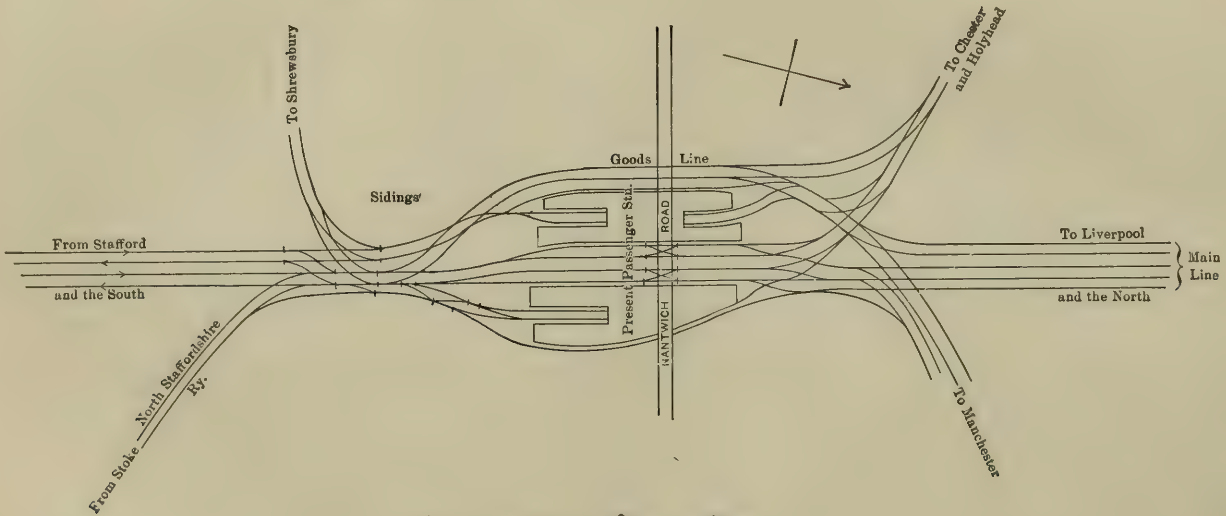
BLACKPOOL (CENTRAL), SATURDAY, AUGUST 15TH, 1903.

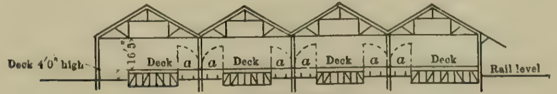
	Arrivals.	Departures.	
Ordinary trains	60	52	
Special trains	37	45	
	97	97	194

Crewe Station. London and North Western Railway.—A glance at the railway map of England will show that Crewe is the geographical center of the London and North Western System. Coming from the south there are no less than six different directions in which a traveler may proceed. On the west there is the Chester and Holyhead Line, together with that running southwest to Shrewsbury and Hereford; the main line leads to Liverpool and the north, and the Stockport and Manchester Section branches toward the northeast, while, on the eastern side of the station there is the North Staffordshire Line. Thus, every passenger train that proceeds from the south to the north, or *vice versa,* or in any other direction, has either to pass through Crewe or to be broken up there and re-formed.

CREWE TERMINAL, L. & N. W. RY.

DIAGRAM SHOWING OLD ARRANGEMENT OF PASSENGER AND GOODS LINES.





a.a. Lifting Bridges

SECTION OF NEW TRANSHIP SHED.

FIG. 19.

The same process takes place with goods trains, this being the depot at which wagons to and from various parts of the system meet, and are either separated or put together, as the case may be.

With lines thus approaching Crewe in every direction, and with the enormous volume of traffic (amounting to 1 000 trains per day) passing through the station, the accommodation became quite inadequate, and the greatest difficulty was experienced in working the traffic, especially the goods, nearly the whole of which had to pass through the passenger station to reach the sidings, which were insufficient and badly situated, being scattered about in detached groups.

In 1896, therefore, after much consideration, a scheme was finally decided upon for remodelling and extending the yard. The works were then put in hand, and, with the exception of the portion connected with the passenger station, are now completed, with the result that the difficulties which were formerly experienced have practically disappeared.

Fig. 19 and Plate LX show plans of the lines as they were before the alterations took place and as they exist to-day. By comparing the two, it will be seen that flying junctions have been substituted for the ordinary connections on the level, thus enabling goods trains to enter the marshalling sidings from every direction without crossing the passenger lines. The sidings, which are capable of accommodating about 2 500 wagons, with suitable reception lines, shunting necks, etc., represent about 40 miles of single track, and are placed so as to enable the up and down traffic to be dealt with separately and conveniently. No less than 5 000 wagons are handled, on the average, in the space of 24 hours.

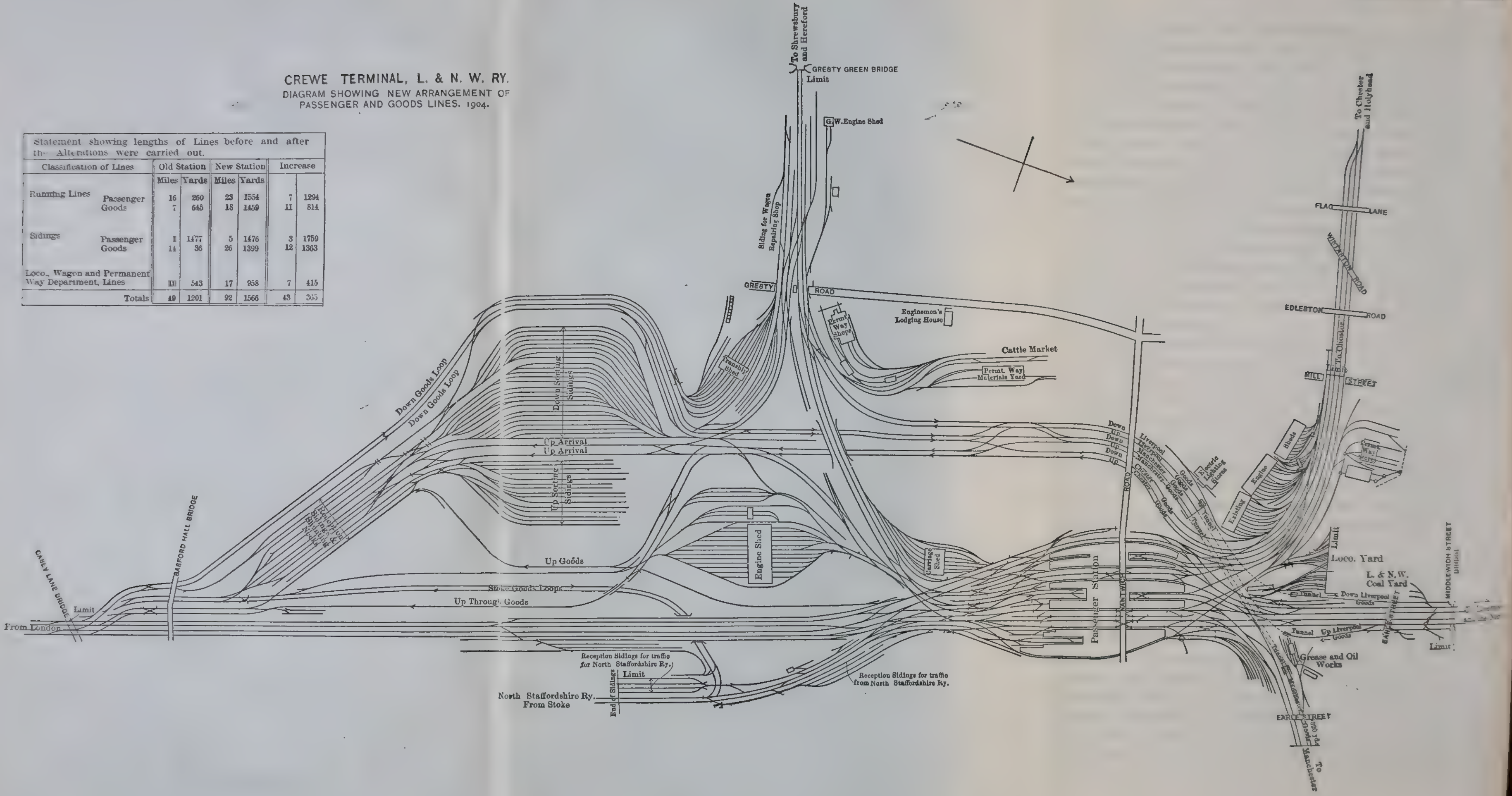
A new tranship shed, the position of which is shown on the plan, has also been built, for the purpose of reloading and sorting the miscellaneous goods traffic which arrives from every quarter, in order that, as far as possible, full truck loads may be made up for the principal towns on the system, instead of transhipping several times over, as was done formerly. An enormous saving has thus been effected in the working of this branch of the traffic, and valuable areas, which were required at other stations, have been released for necessary extensions. The building consists of a single-story shed, 326 ft. long by 188 ft. wide, having four platforms. Seven lines of way enter the shed and run alongside the platforms, which are

CREWE TERMINAL, L. & N. W. RY.

DIAGRAM SHOWING NEW ARRANGEMENT OF
PASSENGER AND GOODS LINES. 1904.

Statement showing lengths of Lines before and after the Alterations were carried out.

Classification of Lines		Old Station		New Station		Increase	
		Miles	Yards	Miles	Yards		
Running Lines	Passenger	16	260	23	1554	7	1294
	Goods	7	645	18	1459	11	814
Sidings	Passenger	1	1477	5	1476	3	1759
	Goods	14	36	26	1399	12	1363
Loco., Wagon and Permanent Way Department, Lines		10	543	17	958	7	415
Totals		49	1201	92	1566	43	365



4 ft. above rail level. The wagons are drawn into the shed by eight electric capstans, four at each end of the shed. There are nine electric and nine hand-cranes, each of 20 cwt. capacity, to assist in the loading and unloading of goods. The goods are wheeled from platform to platform over lifting bridges, which are electrically interlocked with signals governing the admission of wagons into the shed. The platforms are divided into 250 loading berths, lettered and numbered to indicate different destinations. A section of the shed is shown in Fig. 19. During an average day of 24 hours about 600 wagons are received into this shed, and about 500 are loaded and dispatched, the contents varying between 20 000 and 28 000 packages, giving an aggregate of 275 000 tons of goods in the course of a year, or nearly 1 000 tons per day.

The principal advantages derived from the concentration of the transhipment of goods at Crewe are as follows:

1.—Acceleration of the transit of cross-country goods, by more direct loading;

2.—The average load per wagon has been more than doubled since the opening of the shed in 1901, effecting a saving in the use of 100 000 wagons per annum;

3.—Reduction of mileage charges on other companies' stock, by turning it back home at Crewe, instead of allowing it to travel forward to more distant points, as it formerly did in many cases, before the concentration scheme was introduced;

4.—Relief of large stations which formerly had to deal with many of the tranships, with their important town goods.

Originally, the passenger station consisted of two island platforms with accommodations for four through and six terminal lines. Another island platform is being added, under the new scheme, to furnish room for two additional through lines and four more terminal lines, making a total of sixteen platforms beside which trains can be run. The total length of these platforms amounts to 11 650 ft., and the area roofed over is 36 000 sq. yd. Two footbridges, each about 800 ft. long, give access to the various platforms, while a subway of similar length has been provided for the removal of luggage, which is raised and lowered by electric lifts.

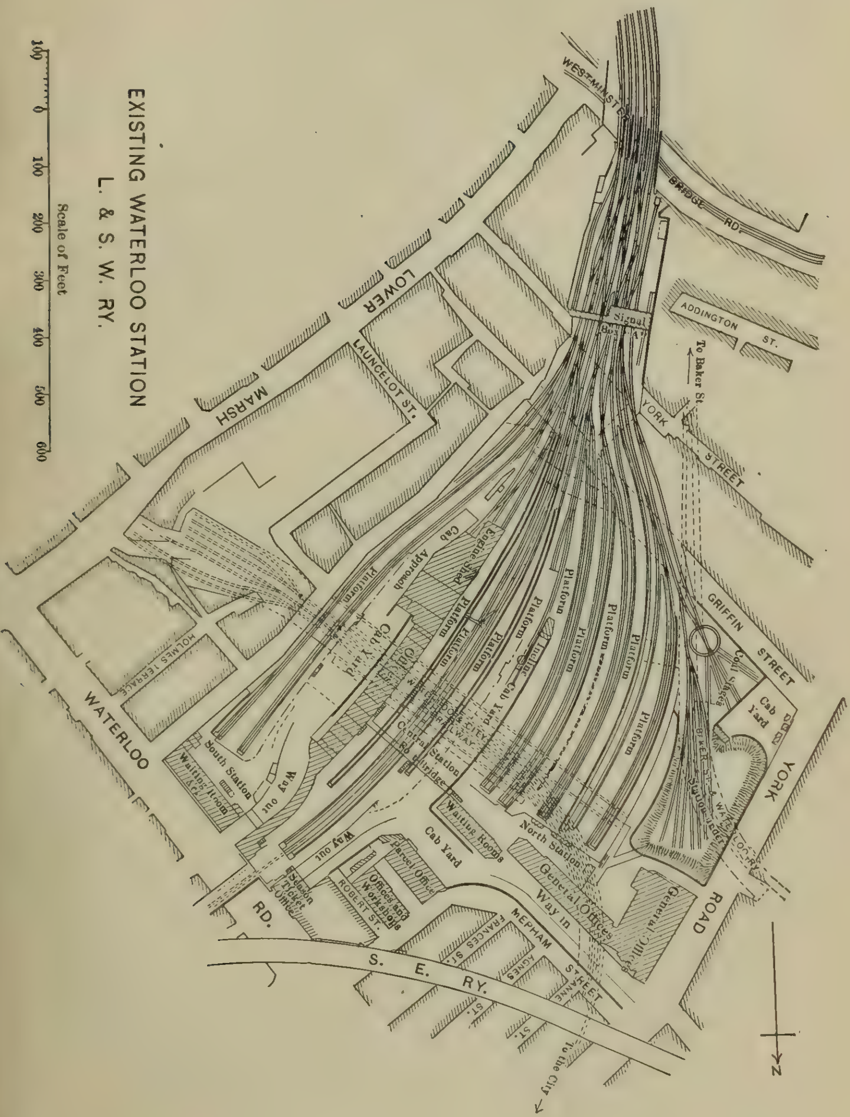
A new engine shed, with accommodation for sixty engines, and a carriage shed capable of holding 147 coaches have also been erected. The station points and signals are worked entirely by electricity from nine signal cabins, the largest of which contains 350 levers.

The electric power is supplied by the company's own plant, which consists of eleven Willans and Robinson's high-speed engines, direct-coupled to the dynamos, supplied with steam from four Babcock and Wilcox boilers, working at 170 lb. per sq. in., and the same source of energy lights the yard, including the signals.

Waterloo Station. London and South Western Railway.—With the ever-growing traffic upon the London and South Western Company's System, in common with that of all railways running into the Metropolis, it has been found necessary to widen the main and suburban lines from time to time, and to provide corresponding relief at the terminus at Waterloo by the addition of lines and platforms. The result is that there are now practically three Waterloo Stations side by side, each with separate approach roads, separate booking offices, and other arrangements, rendering the working of the traffic both difficult and inconvenient. (See Fig. 20.)

With the further widening of the running roads, which is now nearly finished, there will be eight lines in all approaching the station; hence, further terminal accommodation has again become a necessity. The latter is being provided by adding four more lines and platforms on the eastern side. Unlike previous additions, however, which were more or less patchwork, the increased accommodation forms part of a complete scheme for the entire remodelling of the station, the plans for which were prepared by the writer in 1900, as shown upon Plate LXI.

The present work, however, is limited to the widening on the eastern side, which is being carried out by extending the existing viaduct in brick arching and girderwork. With a similar extension on the western side, all that will remain to be done, after constructing the new approach roads and buildings, will be to rearrange the lines and platforms, and thus enable the valuable area already possessed by the company to be used to much better advantage, and a commodious and up-to-date station to be provided with greatly increased facilities for working the traffic.



EXISTING WATERLOO STATION
L. & S. W. RY.

FIG. 20.

It is proposed to describe the plan somewhat in detail, as it affords an example of what, under the particular circumstances, may be regarded as the most desirable arrangement for a terminus in the Metropolis, where a large and continually increasing suburban and main-line traffic has to be dealt with, and which, when completed, will, it is thought, have the distinction of being the largest terminal railway station in Great Britain.

The following primary features had the first consideration:

1.—The convenience of the public in obtaining easy access to the station, either by vehicle or on foot, in connection with both long-distance and local traffic, and for getting rid of the large number of cabs, etc., when these have been discharged.

2.—The arrangement of booking offices, waiting-rooms, etc., so as to enable passengers to join the trains with a minimum of inconvenience and delay.

3.—In the arrangements for main-line and for local traffic, to lay out such a scheme as would enable passengers to interchange readily, as circumstances required. An important feature is that by which it is hoped to solve the problem of luggage, which is recognised as difficult.

4.—The collection and distribution of the large and growing parcels traffic.

5.—While giving commodious platform accommodation, to arrange the lines so that the maximum number of trains may be worked in and out of the station at the same time, the lines being laid so that every platform may be used for either arrival or departure in connection with the long-distance or local traffic.

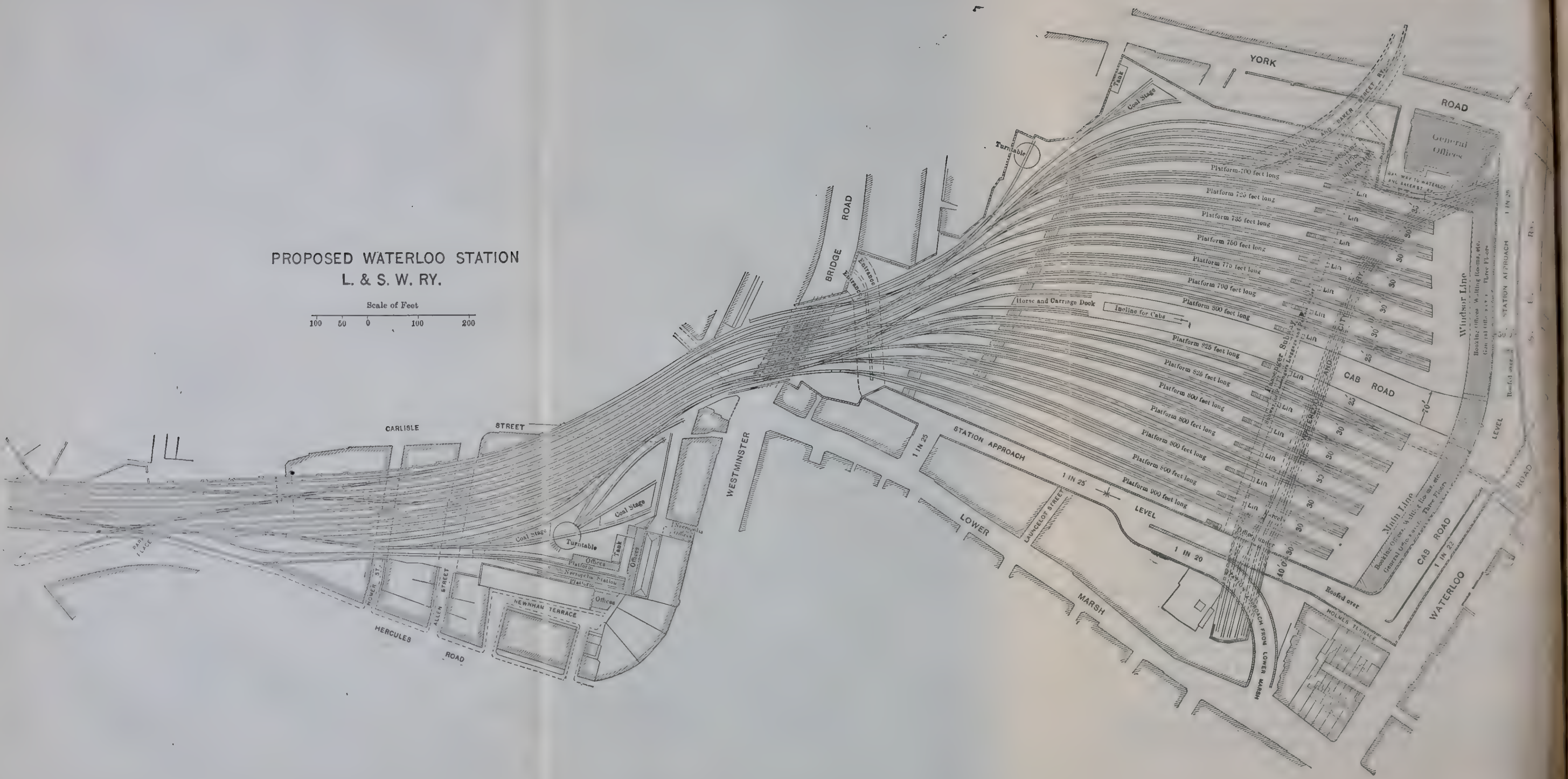
6.—The concentration of the clerical and working staff in convenient offices.

7.—The scheme to be such as could be carried out without diminishing, but rather adding to, the existing accommodation, until better has been provided, and without undue interference with the present traffic arrangements.

After considering the foregoing points carefully, it was decided that an "end-on" station was the only type that would be satisfactory.

PLATE LXI. VOL. LV. PART
TRANS. AM. SOC. C. E. ENGRS.
INTER. ENG. CONG. 1904.
FOXLEE ON
BRITISH RAILROAD TERMINALS

PROPOSED WATERLOO STATION
L. & S. W. RY.



It may be mentioned that the difference in level between the surface of Waterloo Road at the northern end of the station and the platforms is about 22 ft., this difference being a governing factor in the whole matter.

To overcome this height, it is proposed to construct a new approach road, upon a gradient of 1 in 25, along the northern end of the station, up to platform level. This road, which runs by the suburban and main-line booking offices, turns along the eastern side of the station and there connects with the surrounding streets. Along this main approach it is proposed to construct a commodious range of booking offices, waiting-rooms, etc., for both main-line and local traffic, the general offices of the company being provided in three floors overhead.

The proposed station, Plate LXI, will be bisected by a central cab road having an independent entrance under the station arching, the lines and platforms on the east of it being used principally for main-line and long-distance traffic, those on the west side being chiefly for local traffic, the whole arranged so that any platform may be used for arrival or departure, as circumstances may require.

A horse and carriage landing will be conveniently placed at the southern end, and be readily accessible for both the main and suburban lines. Engine turn-tables, tankhouses, coaling arrangements, and sidings, as far as space will permit, for empty carriages (to save light running), will be available on both the main and suburban sides. It is sought to avoid as far as possible the crossing of engines and empty trains over the main lines, this being a most important feature of the scheme.

There will be twenty-five lines, serving eleven double platforms, having a width of 30 ft. at the northern end, and varying from 700 to 900 ft. in length, the total length being about 6 540 yd., or 3¾ miles, and the area about 36 000 sq. yd. A circulating area, 75 ft. wide, runs right across the station in front of the booking offices, enabling passengers readily to reach any platform.

A prominent feature of the scheme is a central passenger subway, which is to be formed in the arching and carried across the whole width of the station, giving access by means of steps to any and every platform. Under this subway is a passageway for luggage, connected also with every platform by lifts, this sub-passage being equally available for general parcels and for milk traffic. An important point in connection with this passenger subway is that it will afford a convenient means of exchanging traffic with the tube railways having their terminus in the arching under the station. The tube already opened runs into the city, and the other, which will be opened shortly, runs across London to Baker Street, thereby connecting with all the northern suburbs. It will also enable passengers, by means of the stairs connected with the platforms, to pass readily into and out of the station in either direction. The booking arrangements at the ends of this subway, and the other facilities proposed, in the shape of cab and omnibus yards on the low level, will accommodate the local passenger traffic well and prevent overcrowding on the high level. Plate LXII is a plan of the proposed arching at the street level.

It is proposed to provide parcels offices on the low level, in the arching, both on the eastern and western sides of the station, and ample space will be available in this arching for the many requirements of the company, which, it is obvious, will have to be met in a large terminal station of this character. Fig. 21 gives particulars of the type of roofing and a cross-section of the subway across the station.

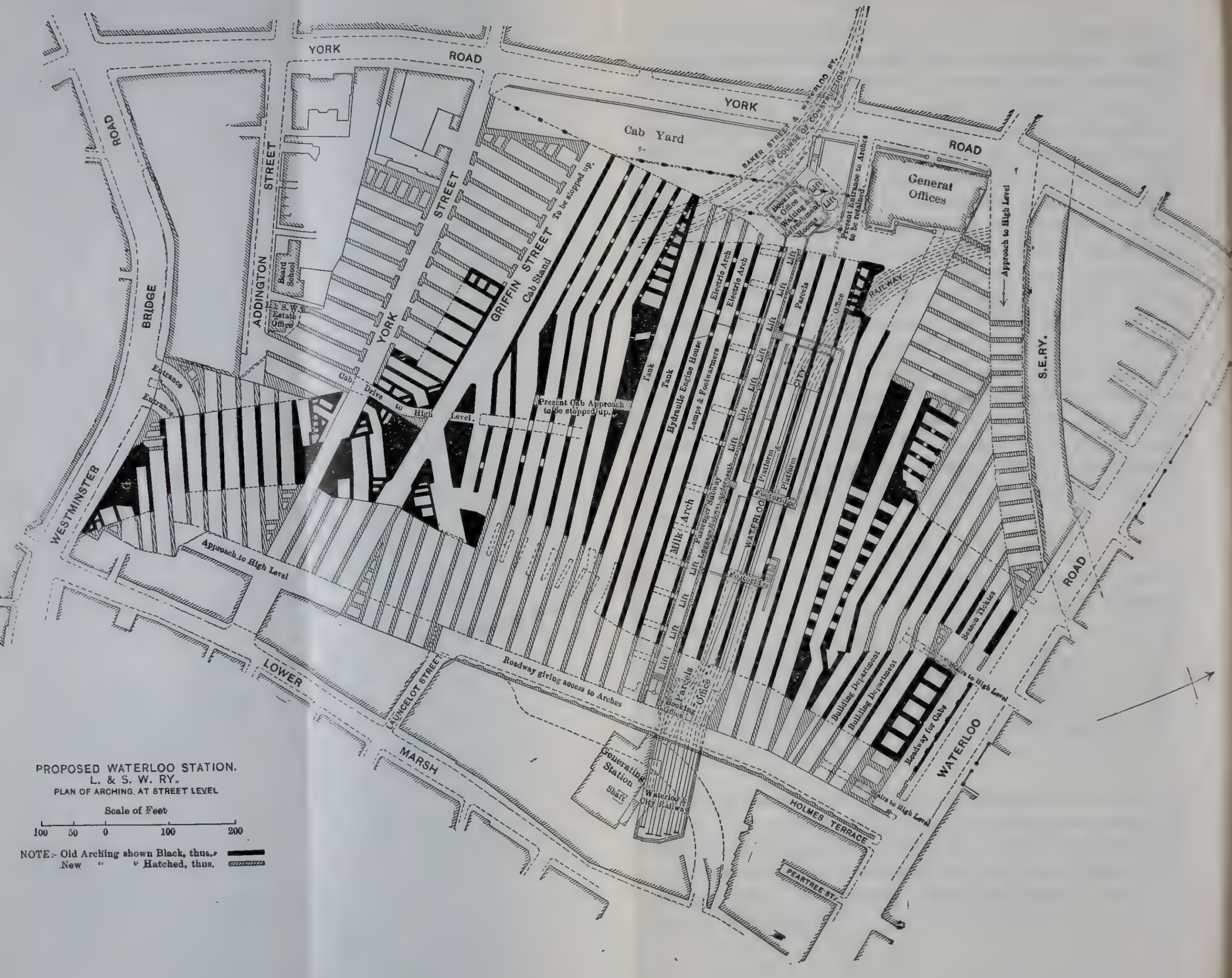
TABLE 1.

	Existing.	Proposed.	Percentage of increase.
Total number of platforms	15	25	66
Total length of platforms	3 718 yd.	6 542 yd.	76
Total area of platforms	19 800 sq. yd.	35 855 sq yd.	80
Longest platform	850 ft.	900 ft.	5.9
Shortest platform	435 "	7 00 "	61
Total area occupied by booking offices, etc.	3 435 sq. yd.	5 075 sq. yd.	48
Total standing room for vehicles	3 784 sq. yd.	18 546 sq. yd.	490
Total area of station	16¾ acres	24 acres	43

The figures in Table 1, which are approximate only, show the extent of the accommodation that exists to-day, and that which will be available when the station has been widened and remodelled.

The station will be controlled by two signal cabins on the northern side of Westminster Bridge Road, with an over-bridge to carry the signals.

PLATE LXII. VOL. LIV. PART
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
FOXLEE ON
BRITISH RAILROAD TERMINALS.

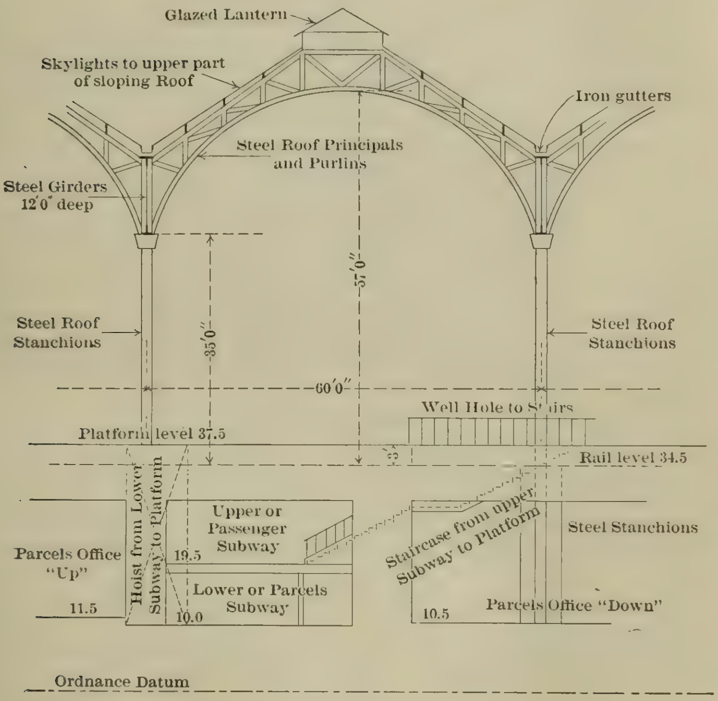


PROPOSED WATERLOO STATION.
L. & S. W. RY.
PLAN OF ARCHING AT STREET LEVEL

NOTE:- Old Arching shown Black, thus.
New " " Hatched, thus.

The number of trains now passing in and out of the station in an average day of 24 hours is about 1 000 in the summer, falling to about 800 in the winter, exclusive of empty trains, light engines, etc., which, if added, would bring the total movements up to about 2 500, or rather more than double the number of actual trains dealt with. At the busiest time of the day, *i. e.,* between 5.30 and 6.30 P. M., about 6 800 passengers pass through the station, and on Saturdays, between 2.00 and 2.30 P. M., this number is nearly doubled. The average number of passengers is about 80 000 per day in the summer, and 50 000 in the winter.

PROPOSED ROOFING FOR WATERLOO STATION,
L. & S. W. RY.



CROSS-SECTION.
FIG. 21.

CONCLUSION.

The foregoing examples may be regarded as fairly representative of existing British practice in the laying out and construction of large terminal railway stations. The subject is not one upon which it is possible to generalise, as the circumstances and requirements in each individual case differ so widely. It may be remarked, however, that most stations of this class in Great Britain are built upon the "end-on" principle, which is found to possess the greatest advantages.

With regard to the details of construction, roofs of small span, varying from 50 to 75 ft, are found to be the most economical to construct and maintain, larger spans being adopted only in special cases. The principals, etc., are usually of mild steel, and the covering either of slate or zinc and ¼-in. rough plate glass. No putty is used in the glazing, for which steel bars, covered with tin-lead, are generally favoured. The columns, where they are high, are usually of cast iron. In small spans they are built up of rolled steel joists and plates.

Concrete or brickwork is usually laid in cement or good hydraulic lime, blue or brindle bricks being generally used for facework where they are readily obtainable, and white glazed bricks for subways and passages.

With regard to platforms, which are carried up to 3 ft. above rail level and finished with ramps, the paving generally consists of moulded slabs of cement concrete, hardwood laid upon concrete being generally used for roadways under cover, and stone setts for those outside.

The all-important question of how to maintain structures efficiently and cheaply is a matter which very properly receives more attention than formerly, whenever their design is under consideration.

The writer's acknowledgments are due to the Engineers and General Managers of all the British railways, as well as to others, for their unfailing courtesy in placing at his disposal the information requisite for the compilation of this paper. Among others, the writer is particularly indebted to Messrs. William Bell (N. E. R.); B. Hall Blyth, M. Inst. C. E., of Edinburgh (for the facts regarding Waverley Station); W. J. Cudworth, M. Inst. C. E. (N. E. R.);

F. J. Dunn (N. L. R); Sir Douglas Fox, Hon. M. Am. Soc. C. E., M. Inst. C. E., and his partners, the engineers of Marylebone Station; Messrs. W. R. Galbraith, M. Inst. C. E. (L. & S. W. R.); Sir Frederick Harrison (L. & N. W. R.); Messrs. C. A. Harrison, M. Inst. C. E. (N. E. R.); J. W. Jacomb-Hood, M. Am. Soc. C. E., M. Inst. C. E. (L. S. W. R.); A. G. Lyster, M. Inst. C. E. (Liverpool Docks); J. A. McDonald, M. Am. Soc. C. E., M. Inst. C. E. (Midland Ry.); W. Matthews, C. M. G., M. Inst. C. E.; W. Melville, M. Inst. C. E. (G. & S. W. R.); C. L. Morgan, M. Inst. C. E. (L. B. & S. C. R.); Basil Mott, M. Inst. C. E. (Central London Ry.); Sir Charles J. Owens (L. & S. W. R.); Messrs. Frank Ree (L. & N. W. R.); J. Robinson, M. Inst. C. E. (for the valuable facts in his paper on Barry Docks); Alexander Ross, M. Inst. C. E. (G. N. R.); P. C. Tempest, M. Inst. C. E. (S. E. & C. R.); E. B. Thornhill, M. Am. Soc. C. E., M. Inst. C. E. (L. & N. W. R.); John Wilson, M. Inst. C. E. (G. E. R.); and W. B. Worthington, M. Inst. C. E. (L. & Y. R.), as well as to the Council of the Institution of Civil Engineers for permission to make use of the *Minutes of Proceedings* in connection with the papers on Marylebone Station and Barry Docks.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 95.

RAILROAD TERMINALS.

FRENCH RAILROAD TERMINALS.

By Ernest Pontzen,* Cor. M. Am. Soc. C. E.

Translated from the French by
Paul A. Seurot, M. Am. Soc. C. E.

The layout and arrangement of terminal stations, as well as of all other railroad stations, have in view either the handling of passengers or the handling of freight. The latter requires installations which simplify and facilitate loading and unloading, while the handling of passengers requires chiefly arrangements which admit of the reduction of the headway of arriving and departing trains.

As no radical changes have taken place in France during the past ten years, in the conditions governing railroad traffic, there has been a lack of impetus in the introduction of new methods.

However, the search for means to operate trains in terminal stations with perfect safety and in the minimum time has led to the adoption of new devices and methods.

To insure greater safety, the working of signals and the movements of switches and other track apparatus have, for many years, been made dependent upon one another by means of an interlocking system. And it was not during the past ten years, but long before, that the great stations of France were equipped, as are those of the United States and Great Britain, with central towers controlling and interlocking all signals and switches.

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* Ingénieur des Constructions Civiles.

The ever-increasing number of interlocking levers, and the increase in length of track they control, made them difficult of operation, and improvements have been made to facilitate the working of all interlocking apparatus. The grouping of signals and other track mechanism according to the various routes, was one of these improvements. The interlocking of the levers is done by groups, each controlling a certain number of switches, signals, etc. This of course reduces the number of maneuvers, but, in spite of improved machinery, increases the work of the operator of the levers.

In order to facilitate the working of the levers, small motors have been placed in the towers, and pneumatic or electrical transmission has been substituted for mechanical transmission.

The Northern, the Paris-Orléans and the Paris-Lyons-Mediterranean Railroads were the first to introduce these improvements, and their example has been followed by other French railroads in their principal stations.*

While these improvements, tending to reduce to a minimum the headway under which trains may be run with safety, were being introduced, new methods were being adopted to accelerate the loading and unloading of freight.

In order to stop the constant protests against the transportation companies, made by maritime towns (where all freight has to be handled twice in the depots, in unloading and loading), the Chambers of Commerce have generally been entrusted with the special work called "quay or wharf service," which consists in unloading the vessels and loading the railroad cars, and *vice versa.* The great ports, such as Marseilles, Le Hâvre, Rouen and others, have spent large sums of money to increase the facilities of the maritime railroad depots.

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*See, in the *Revue Générale des Chemins de Fer*, papers on this subject by M. Cossmann (August, 1902); MM. Cossmann and J. Curiy (January, 1903); MM. Moutier and Sabourin (August, 1903); M. Bleynic (October, 1903), and M. Rodary (December, 1903).

In some ports receiving large quantities of products of one kind, special apparatus has been devised by those interested, in order that the transfer of freight may be made in the most economical and expeditious manner. The methods adopted are generally derived from others which have proved satisfactory elsewhere, and are mentioned here as having been successful, but not as of recent invention.

The Port of Sfax (Tunis) exports every year about 400 000 tons of phosphates brought by rail from Gafsa. The vessels transporting these phosphates generally have a capacity of 2 000 tons, and the transfer from the cars to the vessels is made by Robins belts. Small dump-cars dump the phosphates on belts which raise them to the required height and empty them into the holds of the vessels moored at the quay. The frame supporting the inclined struts between which the conveyor-belts move, is carried on wheels which run on a track parallel to the side of the quay and 100 m. long. One of the rails of this track is laid near the edge of the wharf, while the other is at a distance of 17 m., thus leaving an unobstructed passage along the quay. A petroleum motor, which runs both the frame, or traveler, and the conveyor-belts, is set upon the traveler. The capacity of this plant is sufficient to load 200 tons per hour; that is, to load a vessel in one day. It is, however, about to be duplicated, in order to handle 400 tons per hour.

A similar arrangement has been installed in the Port of Beni-Saf, near Oran (Algeria), to load about 3 000 tons of iron ore per day. The mine from which the ore is taken is within 4 km. of the harbor, and the ore is loaded on small cars of 2.8 tons capacity, which run upon a trestle just above the vessel. In this case, the vessel moves in front of the dumping trestle during the loading.

Passenger stations, also, require, under certain conditions, some mechanical installations. Such installations are especially needed in large stations located either above or below the street level, as is the case in some of the Paris terminal stations; for instance, in the St. Lazare and Montparnasse Stations of the Western Railroad, where the rail level is much higher than the street level, or in the Quai d'Orsay Station of the Paris-Orléans Railroad, where the track is below the surface of the street.

The St. Lazare and Montparnasse Stations are comparatively old and do not contain all the latest improvements. On the contrary, the Quai d' Orsay Station, which has recently been completed, and which is exclusively for passenger traffic, contains all the latest improvements designed to compensate for the drawback of having the tracks and the street at different levels. There are elevators for the use of passengers, and moving inclined planes by which the baggage, at its arrival, is brought to distributing counters on the street floor. To enable the passengers to find their baggage more easily, the ten distributing counters are numbered consecutively from 0 to 9. All baggage having a check number ending with a cipher is sent to the first counter; that having a check number ending with 1 is sent to the second counter, and so on. Thanks to this arrangement, the exit of passengers and of baggage from this underground station is effected as rapidly as, and even more rapidly than, in some surface stations.

The express service, under certain conditions, becomes very important and has to be handled independently of the freight and passenger traffic. Such is the case in the terminal stations of Paris, and particularly at the Austerlitz Station of the Paris-Orléans Railroad, where the quantity of express matter is greatest.

The sorting of innumerable boxes, packages and parcels, arriving generally but a few minutes before the time for the departure of the trains, presents great difficulties.

In spite of a very spacious out-going platform and a great number of employees, frequent errors are made in directing the several articles, and the regularity of this service at certain periods of the year cannot be assured.

The installation of a system of sorting express articles with electrical transportation, inaugurated three years ago at the Paris-Austerlitz Station, may be considered a highly satisfactory solution, because it reduces the labor and the possible errors of direction and also increases the working capacity. The articles are labeled, upon their arrival at the platform, with tags giving their destinations; they are then lowered by freight elevators to underground conveyors consisting of large endless canvas belts run by electric power. In this way they are brought to a central point from which other similar conveyors, running at a higher level than the station platform, carry them to employees whose duty is to pick up the articles as they pass along, and deliver them through chutes leading to the various loading points called for by the labels.

Moreover, express articles are divided into two classes: those that are directly loaded into vans, and those that are put into hampers. The latter are either those addressed to stations receiving too small a consignment to fill a van, or those requiring careful handling.

The detailed description of this installation at the Paris-Austerlitz Station is beyond the scope of this paper; but the reader is referred to a paper on the subject by M. Pons.* When M. Pons wrote his paper, practical results had not yet been recorded. Since then it has been shown that the results have greatly exceeded all expectations. Thus, the number of articles handled reaches an average of 2 400 per hour, and, at certain times, 3 600. At certain periods of the year, the number of articles expressed increases greatly, and there have been days when upward of 40 000 pieces have been forwarded. This work is done regularly, without any appreciable number of errors, and in spite of the fact that the personnel and, consequently, the cost have been reduced by one-half.

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* *Revue Générale des Chemins de Fer*, February and March, 1902.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

Paper No. 96.

RAILROAD TERMINALS.

REVIEW OF GENERAL PRACTICE.

By Elmer L. Corthell, M. Am. Soc. C. E.

The investigations on this subject have extended over a period of five years. The writer was engaged in 1889 as the Consulting Engineer of the proposed Union Passenger Station at Buffalo, N. Y., and was obliged to collect data for the purpose of reporting to the Union Station Company upon certain special features requiring a knowledge of the conditions at other large stations in the United States and other countries. The station has not yet been built, but the writer has continued his examinations, investigations, and correspondence as well, both in the United States and elsewhere, with the intention of presenting the subject to some engineering society. The occasion for the paper has now come, and the main results of the investigations are herewith submitted to the International Engineering Congress of 1904.

It will at once be observed that this paper embraces data from countries outside of the United States. It would be of little value if it did not include a comparison of the characteristic large passenger stations of the world. The extensive comparison of details given in Table 2, Plates LXIII and LXIV, is the main feature of this paper, and represents—as railroad engineers will at once understand—a great amount of research and correspondence, and, the writer hopes, of data useful to engineers, both in the United States and other countries.

While there are resemblances between facilities provided for passengers at terminals in large cities and important railroad centers in various parts of the world, there are distinct differences due to varying conditions as well as to diverse general methods in vogue in various countries.

The physical and transportation conditions in each case require special conditions to meet them.

Generally, large passenger stations may be classified among the following types:

First.—Terminal Stations At or Near the Level of the Streets Adjacent.—Types of these are the existing Grand Central Station, New York City; the Union Terminal Station, St. Louis, Mo.; the South Terminal and North Union Stations, Boston, Mass.; the Dearborn Station, Chicago, Ill.; the Liverpool Street, Euston, Great Central, Victoria, etc., at London, England, and Frankfort, Germany.

Second.—Terminal Stations Elevated Above or Partly Above the Streets.—Types of these are the Jersey City Station, of the Pennsylvania Railroad; the Broad Street Station, of the same railroad, at Philadelphia, Pa.; and the Reading Terminal in that city; the St. Lazare Station in Paris, raised above one street and at the level of others; the Central Station, Antwerp; and nearly all the stations in Berlin.

Third.—"Through" Stations at the Street Level.—Types of these are the Indianapolis Union Station, and the stations at Omaha, Neb., St. Paul, Minn., and Hannover, Germany.

Fourth.—Terminal and Through Stations Combined.—(*a*) At street level, (*b*) above the streets, (*c*) below the level of the streets, and (*d*) partly above and partly below that level; such as (*a*) Buffalo, N. Y.; (*b*) Cologne and Dresden, Germany; (*c*) the proposed Pennsylvania Station, New York City, and Waverley Station, Edinburgh, Scotland, and (*d*) the new Union Terminal now under construction at Washington, D. C.

Fifth.—Some stations are owned and occupied by a single railway company, like those of the Pennsylvania Railroad in Jersey City and Philadelphia, the Liverpool Street, the Waverley, the St. Lazare, etc. Others are owned and operated by a single railroad company,

TAB

LARGE PASSENGER STATIONS

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
CITY	NAME OF STATION	DATE WHEN OPENED	OWNERSHIP		ELEVATION		HEAD - HOUSE OR MAIN STATION BUILDING																
									SPECIAL WAITING-ROOMS		TOILET-ROOMS				RESTAURANT - ROOMS								
			OWNED BY	NUMBER OF OCCU-PANTS	ABOVE STREET	AT STREET LEVEL	GENERAL DIMENSIONS	GENERAL WAITING-ROOM	WOMEN'S	MEN'S	WOMEN'S	MEN'S	BATH-ROOMS	BARBER SHOP	CAFÉ	LUNCH	DINING	KITCHEN	SERVING & PANTRY	STORE &C.	CARRIAGE CONCOURSE	TICKET OFFICES	BAGGAGE
London	Waterloo Station		London & Southwestern R.R. Co.		20′ to 25′ ft. above street level	Reached by incline		1900•′	2219•′		←3664•′→				←6165•′→						Including cab-yards 27400•′	Ticket offices and dependencies 4550•′	Parcels Offices Cloak-room 10705•′
London	Liverpool St. Station		Great Eastern Railway	1	16.5 ft. below street level		490′ x 55′	Gen. 35′ x 26′ x 19′ Suburban 28′ x 24′ x 13.6′ Main Line 35′ x 26′ x 19′ high	23′ x 20′ x 19′ high	None	←47′ x 40′ x 9′6″→				←Restaurant and dependencies 70′ x 40′ x 18′ and three floors above→						St. Level { 300′ x 26′, 105′ x 20′ Platform Level { 140′ x 45′, 106′ x 20′, 420′ x 28′, 52′ x 32′	Main 60′ x 16′ x 12′ high Continental 36′ x 6′2″ x 10′ high	←
Edinburgh	Waverley Station		North British Railway	1	55 ft. below Princes Street	Reached by ramp, stairways and foot bridges		39′ x 18′ x 14′3″ high	1st class 22′ x 16′ x 14.25′ 3rd class 39′ x 16′ x 14.25′	22′ x 18′ x 14.25′	1st class 36′ x 15′ 3rd class 23′ x 16′	63′ x 15′ 48′ x 15′			Refreshment-rooms 1st Cl. 45′ x 35′ x 14.25′ 3rd " 39′ x 35′ x 14.25′		45′ x 35′ x 22′ high				19800•′	2205•′	4140•′
Boston	Northern Union Station		Boston & Maine R.R. and leased lines, and Fitchburg R.R.	2		At street level	116′ x 564′	98′ x 98′ 51′ x 90′ 23′ x 51′	17′ x 24′	Immigrants, waiting-room 18′ x 39′	16′ x 17′ Immigrants 6′ x 8′	24′ x 44′ Immigrants, 8′ x 8′	None	39′ x 39′	None	30′ x 39′	39′ x 68′	19′ x 39′	12′ x 17′	14′ x 21′	98′ x 118′ 32′ x 138′	25′ x 38′	Outward 43′ x 144′ Inward 45′ x 200′
Newcastle-on-Tyne	North Eastern		North Eastern, North British	2		At street level		25′ x 25′	25′ x 25′	25′ x 25′	25′ x 25′	25′ x 25′			25′ x 25′						300′ x 55′		
Buenos Ayres, South America	Plaza Constitucion		Ferro Carril del Sud	1		At street level	Main Building 397′ x 66′ 3 stories Others 426′ x 28′ 2 " " 230′ x 21′ 2 " " 476′ x 33′ 1 "	41′ x 35′ 46′ x 29′	1st class 34′ x 24′ 2nd class 28′ x 16′	None	1st class 17′ x 11′ 2nd class 7′ x 28′	35 x 14	4 9′ x 8′	26′ x 14′	52′ x 33′	None	52′ x 28′ Private room 25′ x 16′	35′ x 18′	25′ x 21′ 19′ x 16′ 2 12′ x 8′ 12′ x 8′	8′ x 6′	Two-arrival 902′ x 20′ Departure 574′ x 43′	36′ x 26′ and 13′ x 13′	Arrival 26′ x 48′ Departure 101′ x 26′
Hannover, Germany	North Railroad Station	Nov., 1880	Köln-Berlin, Frankfurt a M Hamburg, Hannover-Attenbecken, Braunschweig	4	15′ above St.		90′ x 567′	Vestibule 84′ x 100′ x 60′ high 1st and 2nd Cl. 39′ x 45′ x 37′ 3rd Cl. 48′ x 62′ x 37′ 4th Cl. 42′ x 66′ x 37′	1 adjoining 1st and 2nd Cl. 15′ x 42′ x 18′ 1-3rd and 4th Cl. 19′ x 15′ x 16′	None	Under platform 2-13′ x 33′ 1-13′ x 31′ On platform 3-11′ x 13′	Under platform 1-13′ x 22, 1-13′ x 31′ 1-13′ x 33′ On platform 3-11′ x 33′	No Baths 2 Wash-rooms 1-13′ x 10′ 1-13′ x 28′	13′ x 13′	Dining-room on Koln-Berlin platform 22′ x 68′ Cost 29000 m.	3rd & 4th Cl. waiting-rooms have lunch counters	In Head-house 45′ x 66′ x 37′	16′ x 23′	15′ x 23′ 20′ x 20′	10114•′	North and south side of building, available length 567 ft.	27′ x 27′	Inward 63′ x 48′ x 37′ Employees = 1680•′ Outward 63′ x 48′ x 37′
Antwerp	Gare Centrale	July 15, 1808	Belgian State	5	From 15′ to 23′ above St.		184′ x 256 x 213′ high	131′ x 82′	1st & 2nd Cl. passengers 56′ x 59′ x 33′ 3rd class passengers 56′ x 59′ x 33′		1 in each waiting-room 10′ x 13′	1 in each waiting-room 10′ x 13′	None	None	←These are in the two special passenger waiting-rooms→			26′ x 28′	2.43′ x 16	None	In street along train-shed. Covered by balcony	For Belgian station 33′ x 72′ For Foreign station 20′ x 26′	Inward 36′ x 26′ Outward 1-59′ x 131′ 1-49′ x 131′ Cloak 39′ x 85′
New York City	Grand Central Depot	1871	N.Y.C. & H.R. R.R. N.Y.,N.H. & H. R.R.	2	Tracks 1′0″ above St.		118′ x 370′	70′ x 160′ x 35′ high Corridor 18′ x 70′ Ticket Corridor 14′ x 120′	30′ x 29′	30′ x 34′	18′ x 33′	18′ x 34′ 10′ x 26′	18′ x 64′	4 Chairs 6 tub-baths, 2 needle-baths		27′ x 102′	36′ x 58′	←37′ x 88′→		9120•′	37′ x 88′	2-1200•′ total area	Inward 650′ long area = 13000•′ Outward 540′ long area = 16000•′
Washington, D.C.	Union Station			7	Tracks 13-16′ above St.	At level of Plaza also under Plaza	210′ x 630′	128′ x 236′ 30208•′	42′ x 73′ 3066•′ Immigrants— State recep'n—	38′ x 73′ 2774•′ 42′ x 56′ = 2352•′ 30′ x 71′ = 2130•′	37′ x 42′ 1554•′	Main Floor 25′ x 52′ = 1300•′ Basement 64′ x 76′ = 4864•′ = 6164•′		Main Floor 16′ x 25′ = 400•′ Basement 45′ x 65′ = 2925•′		38′ x 118′ 4484•′	80′ x 104′ 8320•′	39′ x 64′ 2496•′	32′ x 102 3264•′	2418•′	105′ x 130′ 13650•′	Lobby 53′ x 105′ = 5565•′ Offices 18′ x 97′ 1746•′	Main Floor 49′ x 124′ = 6076•′ Basement 120′ x 222′ = 26640•′ 49′ x 183′ = 8967•′ Total = 41683•′
Frankfurt a. M., Germany	Main Station	Aug. 18, 1888	Prussian Government Hessische Ludwigs R.R. Cos.	2	Tracks 13.12′ above St.		689′ x 108′ Wing 184′ x 82′ 89500•′	4-46.44′ x 74.13′ = 4′ x 3443•′ 13772•′	2-20.43′ x 24.73′ 2-20.43′ x 26.44′ 2090.8•′	None	46 Toilets 1400•′	42 Toilets 2550•′	4	None	In General Waiting-rooms		2-50.51′ x 74.13′ 7488.6•′	2	2-17.25′ x 17.9′ 2-14.04′ x 19.94′ = 1177.8•′ Pantry in cellar	In Cellar	2 With covered sheds 131.2′ x 24.6′ 6474.8•′	14 2469•′	4 7500•′
Glasgow City	Queen Street Station	1843	North British Railway Co.	1	Elevated and 20′ below street level	At street level	260′ x 500′	1 at high level and 1 at low level	1	1	None	1	None	None	Yes	None	None	None	None	None	1	1	5

* Total annual cost of operation £33,000 about $160,380

TABLE 2.

ER STATIONS IN THE UNITED STATES AND OTHER COUNTRIES.

(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)
N BUILDING								TRAIN-SHED										
CARRIAGE CONCOURSE	TICKET OFFICES	BAGGAGE	EXPRESS	POSTAL	RAILROAD OFFICES	OTHER ROOMS	TICKETS EXAMINED WHERE	GENERAL DIMENTIONS	ARCHES, SPANS OF	MIDWAY LOBBY CONCOURSE	HEAD PLATFORM, WIDTH	TRACKS, NUMBER	TRACK LENGTH, TOTAL LENGTH	PLATFORMS, NUMBER, WIDTH AND LENGTH TOTAL LENGTH		LIFTS, NUMBER AND SIZE		SUBWAYS PASSENGER & BAGGAGE
														PASSENGER	BAGGAGE	PASSENGER	BAGGAGE	
Including cab-yards 27400□′	Ticket offices and dependencies 4550□′	Parcels Offices and Cloak-rooms 10705□′		Parcels and Post Office 500□′	Offices are provided for 10 officials		Passing from carriage to train, also on trains.	Area 8¾ acres	10 spans 50′ to 102′	22950□′ in north and south stations. None for Central Station		18	4050′	30′ to 16′ } x { 850′ to 450			15 Parcel and Post Office lifts 6′x 4′	10′ to 12 wide 8′4 to 11′ high
St. Level { 500 x 26′ 105 x 20′ Platform Level { 140 x 45′ 106′x 20′ 420′x 28′ 62′x 32′	Main 60′x 16′ x 12′ high Continental 36′x 6′2″x 10′ high	←1734□′→					At fence between platform and circulating area	455′ x 163′ 720′ x 150′ 475′ x 190′	42′3½″ to 51′7″ 109′ and 200′ x 88′	175′ x 70′ 270′ x 45′ 200′ x 86′		18 and 2 sidings		18 Platforms 12′6″ to 28′6″ wide 487′ to 920′ long Total length 11 736′			1 8′x 8′	3 Subways
19800□′	2205□′	4140□′				Parcel rooms 12600□′	Not examined	No train-sheds. Sheds are at Haymarket and St. Margarets				19		2 Main Platforms 2 Suburban ". 15 Dock " x 25′ width Total Area=292 680□′			3 for Baggage 1 for Parcels.	
98′x 118′ 32′x 138′	25′ x 38′	Outward 43′ x 144′ Inward 45′ x 200′	Outward 43′ x 176′ Inward 45′ x 178′		Station Master 16′x 20′ & 20′x 23′ Power Plant 2604□′	Telegraph 10′x 12′ Telephone 7′6 x 19 Pullman 12′x 18′ Parcels 14′x 54′ Small wares 1576□′	Rarely examined	456′x 530′ Includes Lobby 50′ wide 246560□′	10 arches. Largest span 120′ average of rest 40′	50′ x 472′	25′	23	23-465′ 10 695′	13 platforms 21′x 455′ Total length 5915	2 platforms 10′x 455′ Total length 910′	2 for Offices 5′x 7′	None.	None.
300′ x 55′							Between concourse and platform	1100′ long and 250′ wide	4 arches 60′ span	400′ x 60′		15	15-1000′ 25′ wide 15 000 lin. ft.				1 9′x 9′	One Subway 8 ft. high.
Two-arrival 902′x 20′ Departure 574′x 43′	36′ x 26′ and 13′ x 13′	Arrival 26′ x 48′ Departure 101′ x 26′	Inward 131′ x 26′ Outward 213′ x 26′	14′ x 11′		Telegraph 14′x 11′ Lost articles 35′x 14′ Information bureau 30′x 10′	Between concourse and track platform	292′ x 597′	1-77′ 1-62′ 1-144′	387′ x 75′	387′ x 75′	10	525 lin.ft. Total 5250′	8 platforms 20′ wide x 525′ long Total length 4200′	Baggage handled by overhead electric carriers	1 5′x 5′	4	None.
North and south side of building, available length 567 ft.	27′ x 27′	Inward 63′x 48′x 37′ Employees =1680□′ Outward 63′x 48′x 37′	Handled in separate building	Separate building	Main offices in separate building Station Supt. and Asst. =7693□′	Emperor's waiting-room 31′x 31′x 22′ Adj. Ladies, room 15′x 14′ " Gents, " 15′x 14′ " Servants, " 15′x 15′	Not stated	289′ x 549′ Center of arch 49′ above rail	2 spans 122′ Open space 30′ Transept 126′ wide center building	None in shed Platforms are approached by tunnels from waiting rooms	These tunnels run transverse to tracks	9	9 x 549′ =4941′	4 platforms 34′x 549′ Total length 2196′	3 platforms 13′x 549′ Total length 1647′	None.	Tunnels to platform 11 Hydraulic lifts. 1 ton capacity	2 Passenger 2 Baggage 1 Mail and Express.
In street along train-shed. Covered by balcony	For Belgian station 33′x 72′ For Foreign station 20′x 26′	Inward 36′x 26′ Outward 1-59′ x 131′ 1-49′ x 131′ Cloak 39′ x 85′	131′ x 197′	1-79′ x 59′ 1-65′ x 59′	6 offices 131′ x 26′	Train waiters, etc. 65′ x 33′ Workman, etc. 538′ x 23′ Technical 10760□′	Not determined	617′ x 236′	106′ above rail Span 212′	92′ x 236′		10	2 492′ 2 525′ 6 820′ Total length =6954′	3 656′x 20′ 3 820′x 20′ Total length = 1428′	No special baggage platforms.	1 6′6″x 5′9″	15 lifts 5′9″x 10′0″	1 Passenger 13′x [illegible] 2 Baggage [illegible]′x 13′ 1 Postal [illegible]′x 16′
37′ x 88′	2-1200□′ total area	Inward 650′ long area=13000□′ Outward 540′ long area=16000□′	2000□′ in building. Most in separate building	Office 180□′	166 rooms 126180□′	Janitor's apartment	Between concourse and track platforms	Main 650′x 200′ Annex 50′x 100′ Intermediate 650′x 32′	Main 200′ Annex 100′	30′ x 200′ 100′ x 100′	10′	19	$2\frac{3}{10}$ miles	5 10′x 600′ 2 14′x 600′ 2 8′x 600′ Total length 5400′	1 72′4″x 600′	1 6′x 6′	6 6′x 16′ 1 8′x 16 1 10′x 16 2 9′x 16′	1 Baggage 18′ x 300′ x 9′6″ high
105′ x 130′ 13650□′	Lobby 53′x 105′ =5565□′ Offices 18′x 97′ 1746□′	Main Floor 49′x 124′=6076□′ Basement 120′x 222′=26640□′ 49′x 183′=8967□′ Total=41683□′	60′ x 420′ special building		38375□′ 3 floors	Bunk-room 5886□′ Train men 40′x 117′=4680□′ Y.M.C.A. rooms 16′x 53′=848□′	Between concourse and track platforms	No train-shed		80′ x 745′ 59600□′	60′	33 20 at Street level, Stub. 13 depressed, through.	640′ to 1370′ 33000′	– 17-700′ long 15′ to 20′ wide	3-700′ long 17′ wide	None.	11.7′ x 15′	1 Baggage 60 wide
2 With covered sheds 131.2′ x 24.6′ 6474.8□′	14 2469□′	4 7500□′	2 Separate buildings 32180□′	1-8.2′ x 14.76′ .111□′	2 Separate buildings 9000□′ each	2 for nobility 24.7′ x 25.8′ Director's room 47.5′ x 26.8′ Ante-room 21.3′ x 26.8′	Between concourse and track platform	551′ x 610′ 336110□′	3-183.68′	54.7′ x 55.0′	58.45′	18	689 to 1411	9 7 21.27′x 984′ 1 24.6′x 984′ 1 31.5′x 984′ 8856′	10 13.78′ to 19.68′ 656′ to 984′ 9512′	None.	10 Baggage 5.41′ x 10.82 10 Postal 5.41′ x 10.82	1 Passenger [illegible] 1 Baggage [illegible] 1 Postal [illegible]
1	1	5	None	None	13 floors 31950□′		Between concourse and track platforms	180′ x 425′	11 spans 170′ lattice-webbed and tied in	30′ x 325′		11	6600′	11 Platforms 6600′	None.	None.	3 8′x 9′ between high and low-level stations.	None.

OUNTRIES.

(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)
RAIN-SHED							APPROACH		HOTEL,	COST OF CONSTRUCTION				TRAINS		
PLATFORMS, NUMBER, WIDTH AND LENGTH TOTAL LENGTH		LIFTS, NUMBER AND SIZE		SUBWAYS, PASSENGER & BAGGAGE	OVER-HEAD PASSAGE-WAYS	OTHER FEATURES AND TOTAL AREA UNDER COVER	GRADES, MAXIMUM, AND LENGTH	CURVATURE, MAXIMUM, AND LENGTH	NUMBER OF ROOMS	LAND AND PROPERTY	BUILDING	APPROACH	TOTAL	NUMBER DAILY	NUMBER BUSIEST HOUR	NORMAL LENGTH LONGEST TRAINS
PASSENGER	BAGGAGE	PASSENGER	BAGGAGE													
30′ to 16′ x 850′ to 450′			15 Parcel and Post Office lifts 6′x 4′	10′ to 12′ wide 8′4′ to 11′ high	8 foot-bridge over Centr. Sta. Stairway to platform.		0.718 about 600 ft.	700 ft. rad. 300′ about.	None.					966	61	
18 Platforms 2′6 to 28′6 wide 87′ to 920′ long Total length 11 736′			1 8′x 8′	3 Subways	1 footbridge with 12 staircases to platforms		1′ in 300′	700 ft. rad. 450′	350 Rooms					1094	83 9 to 10 A. M.	
Main Platforms Suburban ". Dock " x 25′ width Total Area—292 680 □′			3 for Baggage 1 for Parcels.		Bridge to Market St. Stairs to platforms 14′ above rail.		1′ in 78′ 1100′	Straight.	405 rooms being built				£1 500 000 Abt. $7 920 000	1101	76	
platforms 21′ x 455′ Total length 5915	2 platforms 10′ x 455′ Total length 910′	2 for Offices 5′ x 7′	None.	None.	None.	368 000 □′								588	66	
.			1 3′ x 9′	One Subway 8 ft. high.	One overhead passage. 14′6′ over rail.		Level.	Approach straight Station on curve of 660 ft. rad.	170 rooms	£300 000	£400 000		£700 000	Abt. 525	10	
8 platforms 20′ wide x 525′ long Total length 4200′	Baggage handled by overhead electric carriers	1 5′ x 5′	4	None.	None.	Station Master's Office 30 x 16 Book Stall 30′ x 8 2-story building on concourse 60′ x 40′	1 in 177.7 abt. 3214 ft.	Rad. 4166′ Length 2132	None.		£189 300 £88 000 in progress £277 300			60	8	[illegible]
platforms 34′ x 519′ Total length 2196′	3 platforms 18′ x 549′ Total length 1647′	None.	Tunnels to platform 11 Hydraulic lifts. 1 ton capacity	3 Passenger 2 Baggage 1 Mail and Express.	None.	Heating system in cellar.	On east 1 in 400 for 787 ft. On west 1 in 565.7		None.		2 500 000 Marks	1 110 000 Marks	21 260 000 Marks			
3 656′ x 20′ 3 820′ x 20′ Total length — 1428′	No special baggage platforms.	1 6′6″ x 5′0″	15 lifts 5′9″ x 10′0″	1 Passenger 138′ x 23′ 2 Baggage 525′ x 13′ 1 Postal 164′ x 16′	None.	2 men's & 2 women's toilet rooms under train shed 10′ x 13′	1 in 333 Length 3280′		None.	3 500 000 fr.	Head house 7 000 000 fr. Train shed 2 500 000 Viaducts 2 000 000	1 500 000 fr.	26 500 000 fr.	150	12	[illegible]
5 10′ x 600′ 2 14′ x 600′ 2 8′ x 600′ Total length 5400′	1 72′4″ x 600′	1 6′ x 6′	6 6′ x 16′ 1 8′ x 16′ 1 10′ x 16′ 2 9′ x 16′	1 Baggage 18′ x 300′ x 9′6″ high	To restaurant and to Elev. R.R.	258 000 □′	8.7 ft. per mile 0.04 mile	Various expanding 19 tracks to 4	None.					357	31	12 cars.
17-700′ long 15′ to 20′ wide	3-700′ long 17′ wide	None.	11.7′ x 15′	1 Baggage 60′ wide	None.	406 000 □′	0.8 on 2000′ 1.5 on 600′ out	3°0′ to 6°0′ 4700′ total	None.				$4 000 000	231	22	10 cars 700′
8 7 24.27′ x 984′ 1 24.6′ x 984′ 1 31.5′ x 984′ 8856′	10 13.78′ to 19.68′ 656′ to 984′ 9512′	None.	10 Baggage 5.41′ x 10.82′ 10 Postal 5.41′ x 10.82′	1 Passenger 13.94 x 541′ 1 Baggage 9.84 x 541′ 1 Postal 13.25′ x 804′	None.	481 700 □′	1′ in 300′	Rad. 984′ Length 1640′	None.					478	31	
Platforms 6600′	None.	None.	3 8′ x 9′ between high and low-level stations.	None.	None.	130 500 □′	1′ in 44′ for 1005′ 1′ in 41.5′ for 4872′		4 Floors & attics being built.					520		

LAF

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25·
CITY	NAME OF STATION	DATE WHEN OPENED	OWNERSHIP		ELEVATION		HEAD - HOUSE OR MAIN STATION BUILDING																	
							GENERAL DIMENSIONS	GENERAL WAITING-ROOM	SPECIAL WAITING-ROOMS		TOILET-ROOMS		BATH-ROOMS	BARBER SHOP	RESTAURANT - ROOMS						CARRIAGE CONCOURSE	TICKET OFFICES	BAGGAGE	EXPRES
			OWNED BY	NUMBER OF OCCUPANTS	ABOVE STREET	AT STREET LEVEL			WOMEN'S	MEN'S	WOMEN'S	MEN'S			CAFÉ	LUNCH	DINING	KITCHEN	SERVING & PANTRY	STORE &C.				
St Louis	Union Station	Sept. 1, 1894	Terminal Railroad Association	21 Companies		At ground level	606′ x 80′ 48480□′	84.5′x 119′x 17′ 10068□′ Grand Hall (8940□′) 74.5′x 119′x 60′	54.5′x 73′x 15.75 4000□′ Retiring Room 56′x 75′x 15.75′ 4200□′	71′x 55.5′x 15.75′ 3930□′ 2nd class 75.5′x 47.5′x 17′	69′x 18′x 15.75′ 1242□′ 20′x 19′x 17′ 2nd class 380□′	36′x 23′x 17′ 828□′ 2nd class 20′x 18.5′x 17′	None (In hotel)		56.5′x 23′ x 15.75′ 1289□′	86′ x 46′ x 17′ 3956□′	75′ x 65.5′ x 15.75′ 4920□	82′x 26.5 x 15.75′ 2175□′		3340□′	92.5′ x 73′ 6753□′	2200□′	300′ x 30′ 2 stories, 2nd used for storing baggage etc. Offices	5 building 5 compan [illegible]
Jersey City		Rebuilt Train-shed, &c 1899	Penna. R.R. Co.	4	17 ft. above street level		535′x 60′ 195′x 80′	80′x 80′ 6400□′	Retiring Room 44′x 22′ 968□′	None	24′ x 18′ 432□′	48′ x 19′ 812□′	None	34′x 19′ 646□′	40′ x 65′ 2600□′		65′ x 40′ 2600□′	81′ x 80′ 6480□′	80′x 14′ 1120□′	Included in kitchen	None	15′x 20′ and 15′x 15′ 525□′	←	125′ x 2 33750
Philadelphia	Broad St. Station		Penna. R.R. Co.	1	15 ft. above street level		306′x 126′ 38556□′	114′x 110′ 12540□′	81′x 41′ and 30′x 30′	None	34′ x 13′ and 17′ x 15′ 687□′	52′ x 31′ 1612□′	31′x 16′	30′x 17′ 510□′	← 69′ x 77′ 5313□′ →		80′ x 46′				191′ x 62′ and 62′ x 30′	70′ x 20′	←	30000
Philadelphia	Phila. & Reading Terminal	1894	Reading Railway Company	3	26 ft. above ground floor		276′x 140′± 38640□′	1st floor 5055□′ 2nd floor 7857□′	2nd floor 2552□′	2nd floor 493□′	2nd floor 585□′	2nd floor 555□′			2nd Floor 2676□′		2nd Floor 3570□′	In attic	287□		250′ x 75′ 18750□′	1391□′	← 13402□′ —	
Indianapolis	Union Station	1888	Indianapolis Union Ry. Co.	14 Railroads		At street level	147′x 151′	150′x 50′ 7500□′	48′x 42′ 2016□′	1984□′	30′ x 20′ 600□′	30′ x 20′ 600□′		25′x 25′ 625□′		55′ x 43′ 2365□′	55′ x 43′ 2365□′	50′ x 20′ 1000□′			None	1100□′	Baggage-rooms all outside the building	
Chicago	Grand Central	1890	Northern Pacific	3		At street level	837′x 266′	207′x 71′ 14277□′ 25 ft. high	38′x 28′ 1068□′	35′ x 30′ 1030□′					74′ x 66′ on mezzanine floor		None	45′ x 25′ 1125□′			117′ x 149′ 17433□′	1100□′	160′ x 32′	144′x 2 3888
Paris	St. Lazare		Chemin de Fer Quest		Tracks 17 ft. above square		700′x 150′	620′x 59′ Less stairway 33740□′	None	None											220′ x 40′ 8800□′	2600□′	Arrival 20′ x 40′ and 90′ x 25′	
Dresden	Main Station	April 1898	Royal Saxon Government		8 tracks at elev. of 15 ft.	6 tracks at ground level		80′x 55′ 51′ high for 1st & 2nd class 80′x 55′ 51′ high for 3rd & 4th class and 1900□′ more	23′x 17′= 391□′	None	37′x 18′= 666□′	29′ x 17′ Employees 75′ x 24′ Total 2293□′			31′ x 14′ 434□′		50′ x 24′ 1200□′				160′ x 98′ 15680□′ and 4320□′ Total 20000□′	3730□′	15622□′	None
London	Great Central	1899 Not yet completed	Great Central Railway Co.			At street level	340′ x 40.5′ 13770□′ Wings 145′x 21′ and 136′x 70′ 26355□′	35′x 17′=595□′ Concourses used as waiting-room	1st class 30′ x 15′ 3rd class 30′ x 17′ 960□′	30′ x 15′= 450□′	1st class 30′ x 11′ 3rd class 30′ x 11′ 660□′	1st class 42′x 18′ 3rd class 20′x 13′ 1016□′			← 76′ x 40′ 3040□′ →						1000′x 80′ and 340′ x 60′ Porte cochere 90′ x 46′	63′ x 40′= 2520□′ 19′6″ high	2900□′	
Omaha, Neb.	Union Depot	1899	5 Railroads				276′x 80′2″	112′x 50′7″ 41′10″ high 6075□′ total	39′6″ x 24′7″ 15′ high	32′x 24.5′ 15′ high						53.5′x 46.5′ 2488□′		46.5′ x 20.25′ 939□′			276′ x 100′ Uncovered	1200□′	6100□′	220′x 5 and she 22′ 2½′ 43 2 compar
Boston	South Terminal	1899	N.Y., N.H. & H. and B. & A. R.Rs. Boston Terminal Co.		5 ft. above street level	Reached by incline	Total frontage on three streets 3300 ft.	225′x 65′ 28.5′ high 14625□′ 2nd floor Ladies, Parlor 25′x 12′ 300□′	34′x 44′ 1496□′	58′ x 37′= 2146□′ Smoking-room	General 50′x 25′ Pay 22′x 18′ 1616□′ 2nd floor 12′x 12.5′ 150□′	General 30′x 25′ Pay 25′x 25′ 1375□′ 2nd floor 12′x 12.5′ 150□′	None	45′x 35′ 1575□′		73′ x 67′ 4891□′	2nd floor 44.7′ x 28′8″ Public 42.2′x 73.5′ Employees 33′x 44′8″	On 2nd floor 89′x 25′=2225□′ Dining-room, etc., for help 915□′	40′x 15′ 600□′	On 2nd floor 4 storage rooms for kitchen 1246□′	220′ x 35′ 7700□′	85′ x 14′ 1190□′ Parcel-room 60′x 35′=2100□′	Inward 507′x 26′ 13182□′ Outward 562′x 26′ = 14612□′	712′ x 5 35600
Cologne	Cologne Chief Depot	May 1894	Prussian Government	10	About 14.75 ft above street level		538′x 69′ 107′x 106′	105′x 47′7″	8 Rooms=646□′ abt. 10 " =495□′ " 1141□′ "	861□′ 646□′ 1707□′	258□′	904□′	172□′	Yes	Yes	19′8″ x 23′ abt. = 451□′	42′8″x 42′8″ abt. 1829□′ abt.	26′3″ x 32′10″= 861□′	16′5″x 9′10″= 161□′	45′11″ x 26′3″ 1205□′	None inside	98′5″x 13′2″=1291□′ 19′8″x 18′=355□′ 1646□′	52′6″x 134′6″ = 7060□′	45′11″ x 52 =3410

TABLE 2 (Continued).

LARGE PASSENGER STATIONS IN THE UNITED STATES AND OTHER COUNTRI

	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)
							TRAIN-SHED													APPROACH		HOTEL
													PLATFORMS, NUMBER, WIDTH AND LENGTH TOTAL LENGTH		LIFTS, NUMBER AND SIZE							
	BAGGAGE	EXPRESS	POSTAL	RAILROAD OFFICES	OTHER ROOMS	TICKETS EXAMINED WHERE	GENERAL DIMENSIONS	ARCHES, SPANS OF	MIDWAY LOBBY CONCOURSE	HEAD PLATFORM, WIDTH	TRACKS, NUMBER	TRACK LENGTH, TOTAL LENGTH	PASSENGER	BAGGAGE	PASSENGER	BAGGAGE	SUBWAYS, PASSENGER & BAGGAGE	OVER-HEAD PASSAGE-WAYS	OTHER FEATURES AND TOTAL AREA UNDER COVER	GRADES, MAXIMUM, AND LENGTH	CURVATURE, MAXIMUM, AND LENGTH	NUMBER OF ROOMS
	300'x 30' 2 stories, 2nd used for storing baggage etc. Offices	5 buildings for 5 companies 150'x 60', 250'x 60' 150'x 60', 100'x 60' 39000"'	70'x 40' 2 stories 2800"' also 42'x 229' 18th St.	General Office of Terminal Co. in Headhouse above	Telegraph 2000"' Sleeping car. Emigrant, etc. 2nd class waiting rooms	From concourse to track platform	750'x 601' and 606'x 130' 529530"'	2 91' 2 139' 1 141'	606'x 50'	20'	32 under train-shed	310' to 1046' 19 002' clear length.	16 326' to 960' 12.75' to 13' 10766'	None.	None.	None. except in baggage building 9.5'x 6'	None.	None.	472 680"'	0.5% 1400'	14°=410' radius 600'	100
'and 15'	125'x 270' 33750"' ⟶					Concourse to platform	778'x 256' 199168"'	One 256'	535'x 50'	10'±	12	945' 10810'	8 6 13' 2 22' all 778' total 6224'	None.	None. Stairway.	1 7'3"x 14' 2 8'x 22'	None.	From track level to upper deck at Ferry boats.	264 000"'	+ 1% in for 200' + 0.6% in for 500'	None.	None.
20'	⟵ 30000"' ⟶			General offices of Railroad Co.		Between concourse and platform	591'x 306' 180646"'	1 300' 100 ft. high	280'x 50'		16	930' longest 11200' Total	8 20' Pass.	None.	2 8'x 9'	5 for baggage	None.	None.		0.16% in for 1000'	Straight	
	⟵ 13402"' ⟶		1116"'		News room, etc.		502'x 259' 131018"'	1 259' 3-hinge arch 88' high Total height 122'	260'x 50'		13		6 20' wide		6 6.5'x 5' 2 6'x 8'	15 8'x 13'6"	None.	None.	Total size 663'x 267' 178 021"'	700' of 2.4% 1000' of 2.5%	Light	None.
	Baggage-rooms all outside the building			Office building also outside the building	Smoking 35'x 25'		741'x 200' 148200"'				9 pass. 2 freight	741' 8151'		None.	None.	None.	None.	None.				None. ⟵
	160'x 32'	144'x 27' 3888"'		Offices 2nd 3rd and 4th floors	Emigrant rooms. All space above Baggage-room		560'x 119' and 142'6"	1 119' 60 ft. high in center semicircle	260'x 30'		8 main and 3 baggage and 4 prin. tracks	500' 4000'	4 19 ft. 500' 2000'	2 330' 660'	None.	None.	None.	None.	About 685'x 240' 164 400"'			None
	Arrival 20'x 40' and 90'x 25'			Side wings railroad offices		Between waiting-rooms and concourse	500'x 400' 200000"'	6 arches	400'x 40'		31	600' to 700' 18 000"'	14 600' to 700' 20 ft. wide 9100"'	None.	None.	Ladder racks on endless belt for trucks	None.	None.	Average 700'x 700' 490 000"'			Hotel Terminus 275 x 115
	15622"'	None	8753"'			Between concourse and platform	Total area 295354"'	1 30'x 769' 1 101'x 769' 1 193'x 590' 1 105'x 769'	Three concourses. 192'x 50' 173'x 55' 131'x 47'	About 15'	14	Total length 18 592'	8 984' to 2152' 21.3' to 30.5' wide	5 567' to 994' 11' to 18.5' wide	2 8.25'x 7.25' 19 Stairways.	11 10'x 10' 7 Postal 4.5'x 10'		One connecting overhead train-sheds		1.3% 2040'	3° 1910' radius.	None.
high	2900"'		None	Three floors for offices	Parcel-rooms 3500"' Parcel van yard 60'x 45'=2700"'			1 40' 2 50' 1 cantilever. Total span 155'	300'x 100' and 490'x 155' Used also as waiting-room		5	Along platforms or in sidings 2 miles	3 990' 1 30' 2 24' 2970'			1 6'x 4'				0.9% Short.	10° 15' 560' radius Short.	650 bedrooms ⟵
	6100"'	220'x 50' and sheds 22' 2½" 4325"' 2 companies	750"'			Between concourse and and train platform		3 sheds 600'x 21'. Umbrella-shape	317'x 22.5' and 54'x 24'		7 outside of sheds		3 600'x 20' wide		2 from viaduct level to main floor and stairway.	1 8'x 5'6"	None.	Viaduct from street 24'6" above main floor.		0.6% 800 ft. either end.	None.	None.
14'	Inward 507'x 26' 13182"' Outward 562'x 26' = 14612"'	712'x 50' 35600"'	16'x 20' 320"'	215 rooms 101117"' Not including corridors, vaults, stairways, elevators, etc., 4 floors	Power plant 569'x 40' 22760"'	Between concourse and platforms	602'x 570' 112 ft. high in center	Middle span 228' 2 side spans 171' each	610 ft. long 70' to 140' wide about 60000"'	18'	28 on main floor 4 loop 17' below	4 miles under roof Total 15 miles.	13 14' wide 670' to 780' long 69 latter. Total length, 2230' above, 2800' below	6' 7' wide	1 to dining-room on 2nd floor 4 to office floors.	12 about 15'x 6' 4 express lifts Total lifts 24	2 for baggage and express.	None.	403 000"'	Level.	8° 15' about 900'	None.
	52'6"x 134'6" = 7060"'	45'11"x 52'6" =2410"'	75'5"x 39'4" =2970"'	Total floor area for Offices =5165"'	Rooms for high personages 2184"'		853'x 295' 251800"' abt.	Span = 210'3" Height = 78'9"			14	Total Length 18 040'	9 19'8" to 32'10" x 524'10" to 820' 109 750"'	6 6'6" to 23' x 196'10" 1410'5" 88 232"'	None.	8 6'6"x 108'3"	4 6'6"x 10'10"	None.		984'	262	None

COUNTRIES.

	(44)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)	(53)	(54)	(55)	(56)	(57)	(58)	(59)
PROACH		HOTEL. NUMBER OF ROOMS	COST OF CONSTRUCTION				TRAINS			ANNUAL COSTS						REMARKS
S, AND H	CURVATURE, MAXIMUM, AND LENGTH		LAND AND PROPERTY	BUILDING	APPROACH	TOTAL	NUMBER DAILY	NUMBER BUSIEST HOUR	NORMAL LENGTH LONGEST TRAINS	OPERATION		FIXED CHARGES		TOTAL OPERATIONS AND FIXED CHARGES	TOTAL PER CAR	
										TOTAL	PER CAR	TOTAL	PER CAR			
	14 = 410′ radius 600′	100	$4 500 000	Including tracks $2 000 000		$6 500 000	237	39 at 7 to 8 A.M.		$296 636.44		$327 507.40 103 526.51 223 980.89		$520 617.33	$1.577	$103 526.51=revenue from privileges. Fixed charges and operating expenses, taxes, etc. are apportioned among the rail a wheelage basis. Center height of train-shed to skylight 100 ft. Long
n 0′ n 0′	None.	None.					281.	25	8 cars 560′							
n 00′	Straight						538	48 at 5.30 to 6.30 P.M.	10 cars 700′							
.4¢ 2.5¢	Light	None.	Train-shed including sub-floor, cold storage, etc., cost $8.53 per sq. ft. Roof cost $1.15 per sq. ft. of space covered.				417	39								Two floors used for station purposes.
		None.	←	$940 135.19		→	158			$59 836.80	23.7¢	$51 707.43	20.49¢	$11 544.23 add track.	44.19¢ 11.06¢	(53 to 58) This is the average for 10 years, 1889-1898, inclusive. To this should be added track expenses=11.06¢ per car.
		None														(30) Arch extends each side beyond the side posts making full width 142.5′
		Hotel Terminus 275′ x 115′					1200	74								
′	3° 1910′ radius.	None.	$553 263	$3 970 634		$4 523 897	808	49 6 to 7 P.M.		$358 278.16						(38) Elevators are for use of Royalty only.
t.	10° 15′ 560′ radius Short.	650 bedrooms	←	$925 000 Approximate. Not yet completed.			22									All rooms 16′ 8″ high relating to restaurant and waiting rooms. (34) Tracks are 3 ft, below platform level.
ther .	None.	None.	$411 000 Land.	$400 000		$811 000	91	4		Buildings unfinished.						
l.	8° 15′ about 900′	None.	$10 000 000	$4 500 000	$3 000 000 by Railroad Co. outside of Terminal Yard.	$17 500 000	840	88								
′	262′	None.				Abt. $9 520 000	300	13 12 to 1	718′							

but admit the trains of other companies, like the Grand Central Station, New York City. Others are owned and operated by several railroads jointly, organizing a union station company for the purpose, like the Union Terminal Station, St. Louis, Mo.; the Dearborn Station, Chicago, Ill., and the South Terminal Station, Boston, Mass. Others are union stations, *viz.*, companies composed of several railroad companies which admit in joint use the trains of other companies, like the Union Station at Indianapolis, Ind.

Most of the stations above mentioned, and many others, appear in Table 2, Plates LXIII and LXIV, which gives the principal and minor features, as well as essential differences in a much clearer manner than any textual descriptions could, for, in this table, the sixty or more subjects of the stations appear in columns in such a way as to bring the data of the stations under each other for comparison.

Twenty-four representative stations have been selected for this comparative table. Many others might have been taken for the purpose, but it is believed a sufficient number, with sufficient differences, have been chosen to bring out the features of greatest interest.

It will be noted that there are some blanks. This is due to the fact that the information was not available.

A circular letter, requesting information in reference to the various items covered by the column headings of Table 2, was sent by the writer to the engineers or other officials of many large passenger stations, beginning in 1898 and continued up to the present year.

Table 3 gives the result of a recent investigation of six large passenger stations in the United States, most of which are included in Table 2, Plates LXIII and LXIV. The data in Table 3 relate especially to the operation of the stations. The information is condensed into a small compass by giving the maximum, minimum and average figures of the six stations. The stations considered are:

Reading Terminal, Philadelphia, Pa.;
Broad Street Station, Pennsylvania Railroad, Philadelphia, Pa.;
South Terminal Station, Boston, Mass.;
Lake Shore and Rock Island, Chicago, Ill.;
Union Terminal Station, St. Louis, Mo.;
Grand Central Station, New York City.

As these are representative stations, Table 3 will offer information of value.

Evidently, no tables, however detailed, can bring out all features of interest.

As to the movement of trains and the number of passengers handled, which prove the capacity of the stations and their ability to handle great crowds, the enormous number handled on unusual days, like bank holidays in London, Saturdays and Sundays in Paris, and on extraordinary occasions, does not appear in these tables, which show only regular scheduled trains made up from the official time-tables.

TABLE 3.—SPECIAL INFORMATION RELATING TO SIX LARGE UNITED STATES PASSENGER STATIONS.

Results of Investigations in the Winter of 1903.

Items.	Maximum.	Minimum.	Average.
TRAIN ROOM:			
Number of tracks	32	11	20
Scheduled trains per track in 24 hr	32.6	7.4	23
“ “ “ “ busiest hour	2.8	1.2	2.2
Passengers per foot of width of all platforms, in 24 hr	446	236	337
TRAINS:			
Scheduled trains in 24 hr.:			
Through	249	46	151.8
Suburban	580	80	275.3
Total	829	191	427.1
Scheduled trains in busiest hour:			
Through	38	3	17
Suburban	50	2	26
Total	81	27	43
Maximum number of trains in 24 hr	854	213	494.3
“ “ “ “ “ 1 hr	97	31	46.6
PASSENGERS:			
Average number per scheduled train:			
In 24 hr	178	80.8	115
In busiest hour	251	100	188
On scheduled trains in 24 hr.:			
Through	22 000	4 566	13 641
Suburban	33 839	16 701	24 509
Total	80 318	21 267	45 820
On scheduled trains in busiest hour:			
Through	3 557	709	1 866
Suburban	6 092	2 000	4 581
Total	7 991	4 000	6 448
Maximum in 24 hr	200 000	34 598	104 195
WAITING-ROOM:			
Maximum number of passengers per square foot of area	7.9	1.9	5.6
Average number of passengers per square foot of area	4.4	1.1	3

TABLE 3.—(*Continued.*)

Items.	Maximum.	Minimum.	Average.
Concourse:			
Area in square feet	60 000	14 814	26 657
Width of concourse, in feet	89	35	53.3
Width of gates to trains, in feet	11.7	3.5	8.3
Total width of all exits, in feet	162	46	96.5
Passengers in 24 hr.:			
Per square foot of area	3	1	2
Per foot of exit	1 076	284	556
Maximum passengers in 1 hr.:			
Per 10 sq. ft. of area	10	4	6
Per foot of exit	221	87.1	165
Toilet-Room:			
Passengers in 24 hr. per fixture:			
Water-closets	2 333	686	1 227.3
Basins	7 000	1 933	3 724.1
Urinals	3 878	863	2 406.3
Booths:			
Number of telephones	14	1	7
Parcel:			
Area, in square feet	1 625	195	614
Linear feet of shelving	2 294	50	837
Number of parcels in 24 hr	2 200	2 000	2 100
News—Area, in square feet	480	180	337
Flower—Area, in square feet	500	15	173
Confectionery—Area, in square feet	500	25	241
Cigar—Area, in square feet.	520	200	360
Restaurant:			
Seating capacity:			
Lunch counter	185	38	77
Dining-room	330	42	20
Passengers in 24 hr.:			
Per square foot of area	70	4	17
Per seat	1 108	115	305
Cabs:			
Area, in square feet of cab stand	16 320	2 952	880
Linear feet of platform at cab stand	250	40	159
Baggage:			
Pieces in and out in 24 hr.:			
Average	5 000	1 200	3 675
Maximum	12 000	1 500	7 198
Pieces per train	16	3	10
Number of passengers per piece	35	8	15
Area per piece, in square feet	12	2	7
Pieces per linear foot of counter	100	18	64
Postal Matter:			
Tons in 24 hr.:			
Average	315	12	169
Maximum	350	23	183
Area, in square feet	12 640	720	3 552
Area per ton, in square feet	72	12	43
Linear feet of platform	112	4	45
Scales	1	1	1

In addition to loaded trains departing and arriving, there are other movements required. The arriving trains, after being unloaded, are hauled out empty to the coach yards, possibly some distance from the station. When the time arrives for trains to depart, the empty trains must be hauled back to the station. The locomotive which brings in the loaded train cannot haul it out, and must be uncoupled to follow it out, to go to the roundhouse or yard.

Table 4, a condensed table of movements found in the station time-tables of the South Terminal Station, Boston, and the Grand Central Station, New York City, gives an idea of the extra movements required by all these trains and engines.

TABLE 4.—RECAPITULATION OF TRAIN MOVEMENTS.

SOUTH TERMINAL STATION, BOSTON, MASS.

		Week-day trains.	
B. & A. R. R.		218	
N. Y., N. H. & H. R. R.			
Providence Division	310		
Plymouth Division	242		
Midland Division	91	643	
Total regular trains		861	861
Drafts to and from storage yards			433
Light engines to and from engine-houses			370
Total movements to and from terminal			1 664

GRAND CENTRAL STATION, NEW YORK CITY.

N. Y. C. & H. R. R. R.			
Harlem Division	103		
Hudson Division	129	232	
N. Y., N. H. & H. R. R.		125	357
Harlem Line storage trains			109
Storage trains, Forty-sixth Street yard			227
Light engines to and from engine-houses			345
Total movements to and from terminal			1 038

As ninety regular scheduled trains (see Table 2) arrive and depart in the busiest hour (5.03 to 6.03 P. M.) at the South Terminal Station, Boston, the number of movements required to accomplish this regular hourly work is very great, and the signal and switch handling and interlocking mechanisms must necessarily be of the most approved kind, and must be handled incessantly.

Even in stations which in importance do not rank with the foregoing, it is quite common to find a great number of movements.

PLATE LXV. VOL. LIV. PART F.
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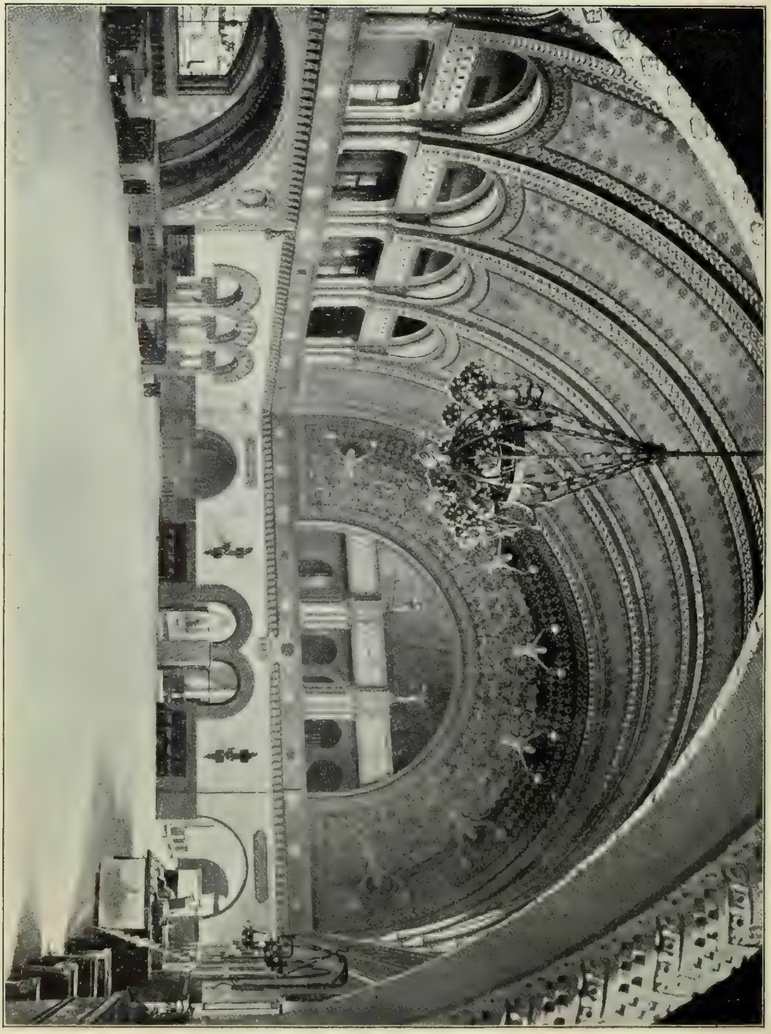

Grand Hall. St. Louis Union Terminal Station.

In 1901, at the Union Station, St. Paul, Minn., there were, in the busiest hour of the day (8 to 9 A. M.), ninety-six movements, including empty trains and light engines. While there are ten tracks in the station, 92% of these movements was handled on six tracks. This station is used jointly by ten important railroads, mostly through trunk lines. One million pieces of baggage are handled per annum, or 2 216 per day. The daily average at the Grand Central Station in the same year (1901) was 2 654 pieces. The St. Paul station has, since that date, been enlarged, and now has fourteen tracks, with a minimum length of 1 435 ft. and a total length of 13 960 ft.

A large volume would be required to describe and illustrate the twenty-four stations mentioned in Table 2. It is possible, in the space allowed, to describe briefly only one or two of each type mentioned, *viz.:*

First.—Terminal stations at the street level.

Second.—Terminal stations, elevated or partly elevated.

Third.—Through stations at the street level.

Fourth.—Terminal and through stations, combined.

To illustrate the first type, the St. Louis Terminal Station, the Dearborn Station, Chicago, and the station at Frankfort, Germany, have been selected; for the second type, the Reading Terminal, at Philadelphia, and the St. Lazare Station, at Paris; for the third type, the Union Station, at Indianapolis, and the North Railroad Station, at Hannover, Germany; for the fourth type, the new Union Terminal, at Washington, D. C., the Waverley, at Edinburgh, and the Main Station, at Dresden, Germany.

First.—Terminal Stations at the Street Level.—The St. Louis Terminal Station is one of the largest in the world, as it has more passenger tracks than any other—thirty—with room for two more. However, it does not have as many arrivals and departures as some others, its trains being largely through trains of the twenty-two important trunk lines which use the station, and it does not have a large suburban traffic. The trains approach from two directions: From the east, over the two Mississippi River bridges, and from the west.

The original plan of the immediate approach had serious objections, as the tracks crossed each other. Radical changes are now nearly completed. Fig. 22 shows the new approach. By re-arranging and re-grouping the tracks they have been increased in number from four to six.

The plan of the ground floor of the station, the "Midway," or concourse, and the station end of the track are shown in Fig. 23.

The general character of the interior is well illustrated by Plate LXV, which shows the "Grand Hall," or main waiting-room on the second floor.

The station is owned by the "Terminal Railroad Association of St. Louis." The roads using it, and forming this association, compose the proprietary company. The total cost of the station was $6 500 000, the real estate costing $4 500 000 and the buildings $2 000 000.

The cost of operation during 1898 was as follows:

Rental	$327 507.40
Less revenue from privileges	103 526.51
Net rental	$223 980.89
Actual operating expenses and maintenance	296 636.44
Total cost per annum	$520 617.33

The average charge per car for that year was $1.58. The cost is apportioned among the railroads using the station on a "wheelage" basis. This word is not to be understood as referring to wheels, but to cars (coaches), and the charge is on the basis of "equalized cars." The following paragraph from the agreement between the associations and the various railways occupying the stations will explain the above term and show clearly the manner of apportioning the costs:

> "An accurate record shall be kept by the Terminal Company of all passengers, baggage, mail, express, sleeping, dining and special cars, in and out of the said Union Station, during each calendar month, and said Railway Company shall pay said Terminal Company such proportion of said balance as the number of such cars of said Railway Company in and out of the said Station, bears to the whole number of such cars, in and out, of lines using said Station facilities during the month; and in so ascertaining the number of such cars in and out, cars hauled in trains, the run of which terminates within 37 miles of said Union Station, shall be counted as one-third part of a car, in all other cases as one car."

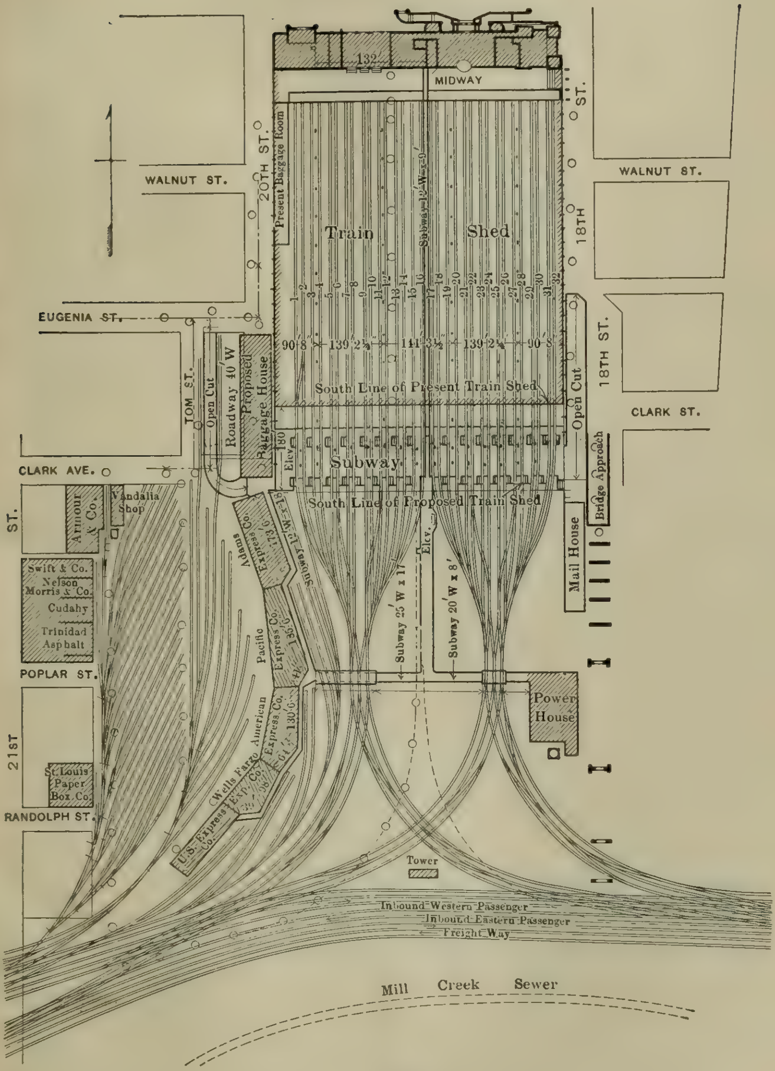
132
MIDWAY
ST.
20TH ST.
WALNUT ST.
WALNUT ST.
18TH
Present Baggage Room
Train
Shed
Subway 12' W x 9'
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32
EUGENIA ST.
90' 8"
139' 2¼"
141' 3½"
139' 2¼"
90' 8"
18TH ST.
TOM ST.
Open Cut
Roadway 40' W
Proposed Baggage House
South Line of Present Train Shed
Open Cut
CLARK ST.
CLARK AVE.
Elev.
180
Subway
Bridge Approach
South Line of Proposed Train Shed
ST.
Armour & Co.
Vandalia Shop
Adams Express Co.
Subway 12' W x 16'
Elev.
Mail House
Swift & Co.
Nelson Morris & Co.
Cudahy
Trinidad Asphalt
Subway 25' W x 17'
Subway 20' W x 8'
Pacific Express Co.
POPLAR ST.
Power House
American Express Co.
21ST
St. Louis Paper Box Co.
Wells Fargo Exp. Co.
RANDOLPH ST.
U.S. Express Co.
Tower
Inbound Western Passenger
Inbound Eastern Passenger
Freight Way
Mill Creek Sewer

FIG. 22.

The Dearborn Station, Chicago, Ill., is a terminal station at street level. It is owned by a terminal company—the Chicago and Western Indiana Railroad Company—and is occupied by six trunk lines as their passenger terminals in Chicago. There are two main-line entrance tracks and ten tracks in the station. The total area under cover is 137 000 sq. ft. The cost of the building was $621 938.79. The total cost of operation in 1903 was $210 111.71. The annual cost of operation per car was $69.85. One hundred and twenty trains, mostly through, long-distance trains, arrive and depart daily; in the busiest hour there are nineteen trains.

The Main Station, at Frankfort-on-the-Main, Germany, is owned jointly by the Prussian Government and the Hessian Ludwigs Railroad Company. It is practically a street-level terminal station, the entire area in front and on the sides having been raised and embellished with fine approaches, plazas, grass plots and parks. The approach tracks are about 13 ft. above the streets.

The general railroad approach differs from that of the station at St. Louis, as groups of tracks come into it direct, while those from lateral directions enter in two groups of approach track, much like the new plan at St. Louis, making four groups in all. See Plate LXVI.

To prevent grade (level) crossings of the various approach tracks, they are placed at different levels when some little distance from the station.

The train-shed is not as large as that at St. Louis, being 551 by 610 ft., with an area of 336 110 sq. ft., while the St. Louis train-shed is 606 by 700 ft., with an area of 424 200 sq. ft., and there are only eighteen tracks at Frankfort. A comparison of other features may be seen in Table 2.

Plate LXVI shows the general plan of the station, as well as the freight stations and the approaches, also the relations of all these features to the City of Frankfort. The monumental character of the station is shown by Fig. 1, Plate LXVII, a photographic view of the front of the station, and by Fig. 2, Plate LXVII, which shows a part of the interior of the train-shed. This shows clearly the great steel arches and the substantial and permanent character of the platforms.

Second.—Terminal Stations, Elevated or Partly Elevated.—The "Reading Terminal," at Philadelphia, is a characteristic station of

PLATE LXVI. VOL. LIV. PART F.
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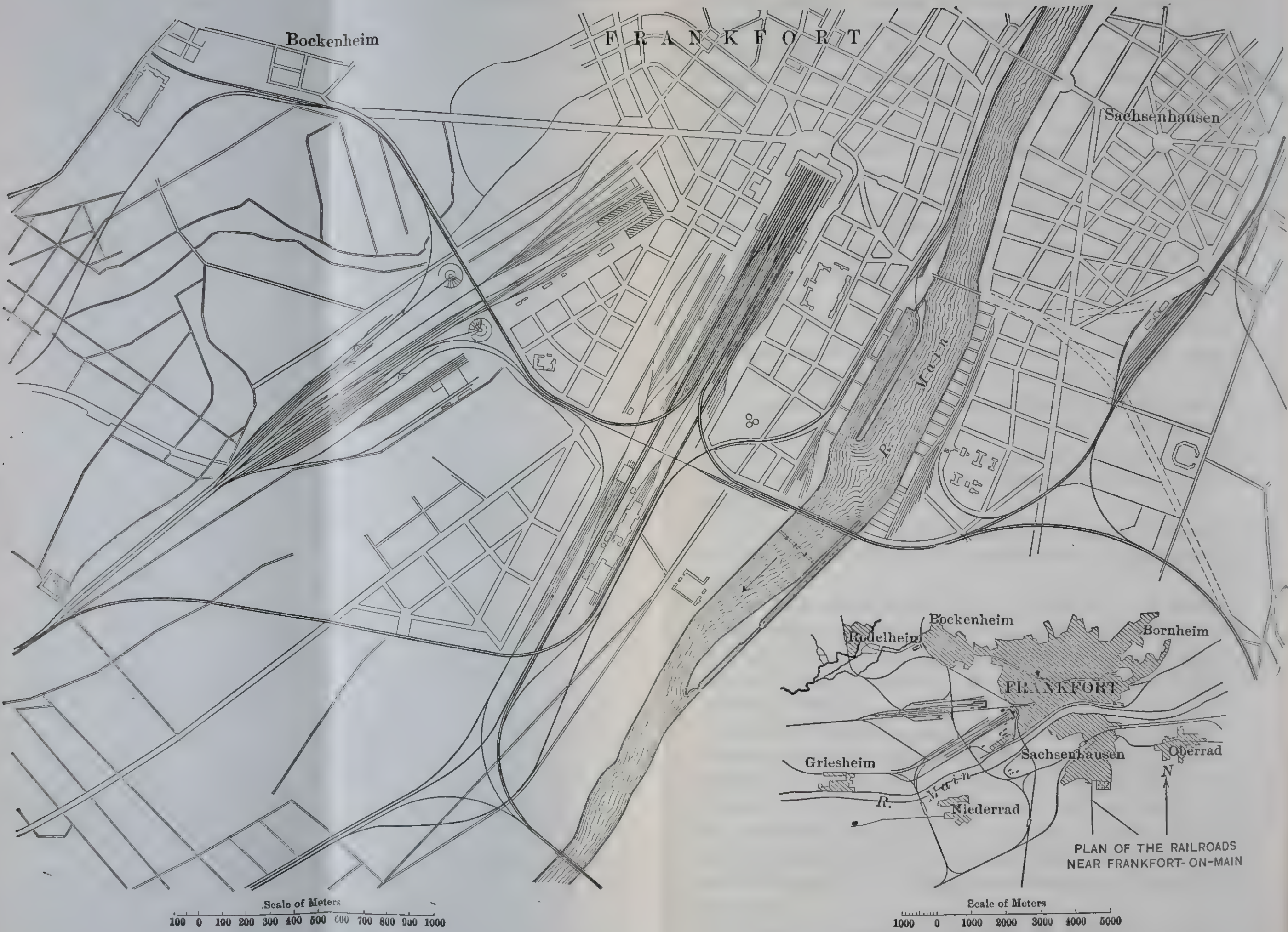
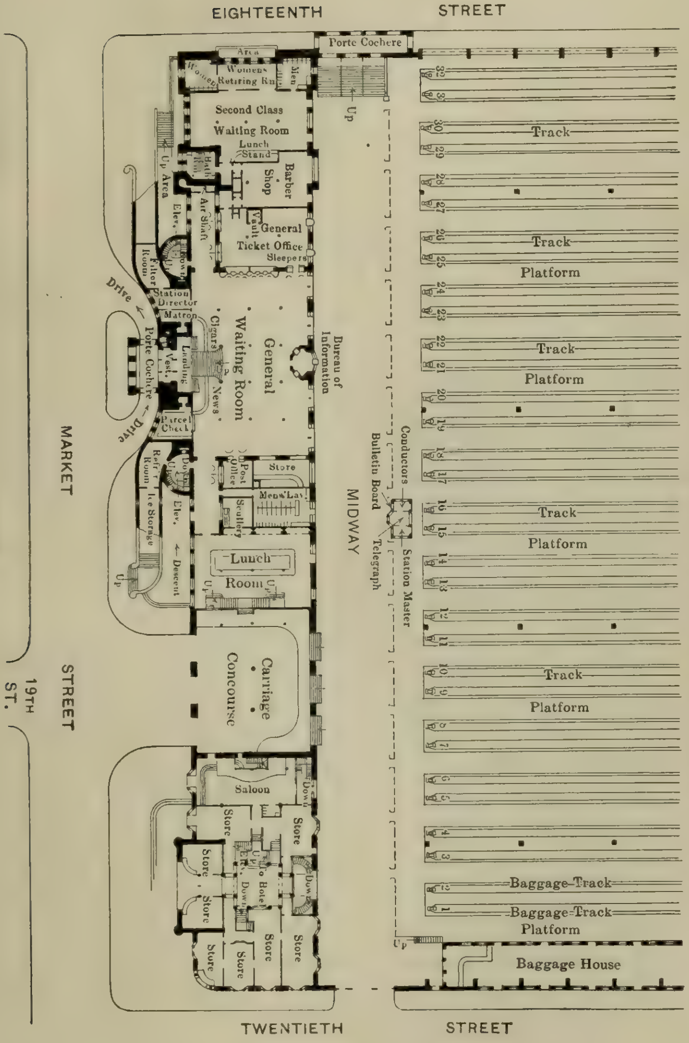
CORTHELL ON
RAILROAD TERMINALS.

RAILROAD TERMINAL AT FRANKFORT-ON-MAIN



PLAN OF THE RAILROADS
NEAR FRANKFORT-ON-MAIN



PLAN OF GROUND FLOOR SAINT LOUIS UNION STATION.

FIG. 23.

the second type, elevated above the streets. Its general and detailed features are shown in Table 2. The train-shed has a single metallic arch, three-pointed, hinged at the crown, and covering the entire width of the tracks. The width of the arch at the springing, between the centers of the piers, is 259 ft. 8 in. The height is 88 ft. 3 in. The length of the train-shed is 502 ft. The total length of the station, including the head-house, is 663 ft.

Starting from thirteen tracks in the station, they reduce to five tracks, 350 ft. from it. About 1 650 ft. from the end of the train-shed, the tracks separate into two lines of two tracks each.

The terminal yard is reached over an elevated structure, with either plate-girder bridges over the street, or stone arches, or plate girders carried on columns. The two separate double-track lines are carried on an elevated structure more than 0.5 mile in length. The tracks are about 25 ft. above the street level. The station, proper, is in the second story of the head-house, the ground floor being used for entrance, waiting-rooms, ticket offices, baggage-rooms, etc. The general and administrative offices are located above the second story. The ground floor, under the train-shed, is used as a large market, and cold storage and refrigerating apartments.

The main waiting-room is on the second floor, and is very lofty, occupying two stories in height. The dining-rooms, lunch-rooms, smoking-rooms, etc., are on this floor.

There are two large passenger elevators between the ground floor and the second story and also a broad stairway. Each baggage-room has two elevators (lifts) to carry large baggage trucks to the train-shed floor. Four more elevators serve the upper or office floors.

There is a cab stand below, 75 by 250 ft., a concourse above, running the whole width of the building and 50 ft. wide. The floor of the train-shed is constructed of buckle plates carried by plate girders. There is a layer of concrete over the plates and then 1 in. of Neuchatel asphalt over that. The cross-ties of the track are laid on asphalt concrete, the platforms being of the same material. The surface of the platforms is 8 in. above the top of the rails. Large frames filled with heavy hammered glass are built into the platforms to furnish light to the apartments below.

The building is a monumental structure, Italian Renaissance in style. The exterior faces on the street fronts are of pink granite to the first story, and, above that, of pink brick and cream terra cotta.

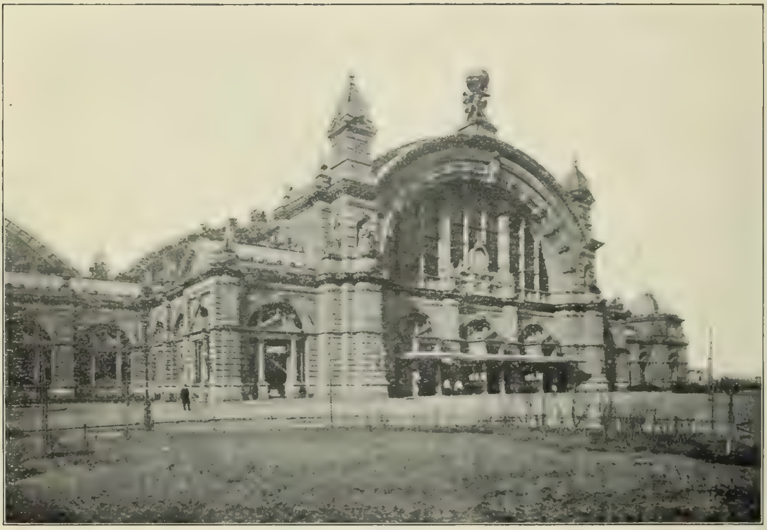


FIG. 1.—FAÇADE OF FRANKFORT TERMINAL.

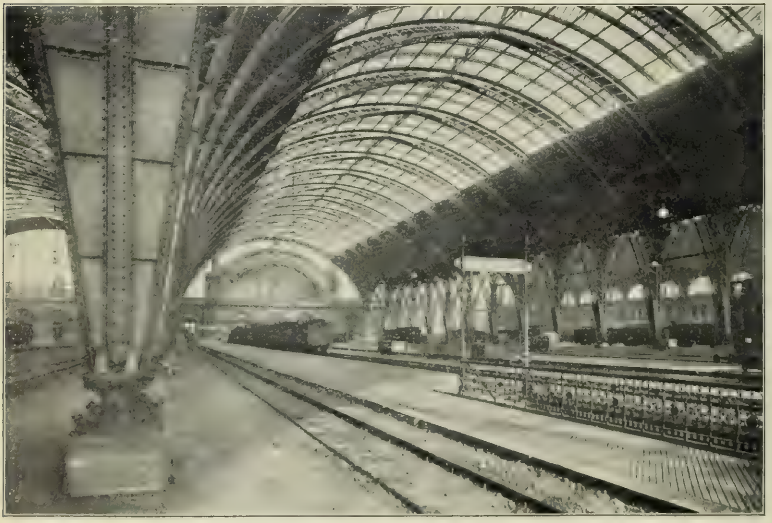


FIG. 2.—TRAIN-SHED, FRANKFORT TERMINAL.

Some items of cost are of interest. The head-house cost $35.95 per sq. ft. of superficial area, or 23.1 cents per cu. ft. of contents. This cost is for construction alone, and does not include heating, lighting, elevators, water supply, etc. The train-shed, including foundations, cost $8.53 per sq. ft. of surface covered. The structural steelwork of the roof of the train-shed cost $1.15 per sq. ft.

A complete description of this station may be found in the *Transactions,* Am. Soc. C. E.,* together with plans, sections, photographs, etc., of the train-shed and the head-house.

The St. Lazare Station, of the Western Railway of France, is a good illustration of a great station, partly elevated and partly at the street level.

In front, the Rue St. Lazare is considerably below the level of the tracks, but, on the eastern side, at the passenger exit, the station is at the level of the Rue d'Amsterdam. The ground ascending still, the Rue de Londres is considerably above the station tracks, necessitating, a little further on, at the Rue de St. Petersbourg, a car lift, about 32 ft. in height.

There are thirty-one tracks in the station; twenty-seven passenger train tracks and four tracks for locomotive and other station service. About 0.25 mile from the signal station, just outside the station, the tracks converge into six tracks, and pass through a tunnel about 1 000 ft. long. They then pass through a deep cut, 0.75 mile from the station signal bridge. They then diverge, two turning to the west and four continuing toward the north. Near the point where the tracks diverge, there is a very large terminal yard.

This is one of the best equipped terminal stations in the world. All parts of it, including passenger station, freight station, roundhouses, shops and yards are well supplied with hydraulic power and electric power and light.

Plate LXVIII shows the general layout of the station and tracks.

There are some very interesting and novel features in and about this station. It covers 27 acres; and has about 1 200 trains arriving and departing daily, equal to any in the world. The suburban trains in this station must be handled very quickly, to accommodate the immense business. These trains come in loaded, and, almost immediately, go out loaded. A special mechanism in the shape of a combined traverse-turntable, Fig. 24, is provided at the station end of several tracks, so that the locomotive which has come in head-on may be immediately uncoupled, moved over to an adjoining service track and turned at the same time, sent out of the station head-on to the coal chutes and water station, and backed down to its train by the time this has been unloaded and loaded up again. This plan saves time, saves movements of trains, and permits the locomotives of the suburban trains to travel always head-on, coming and going out. The location of these traverse-turntables may be seen on Plate LXVIII.

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* "The Philadelphia and Reading Terminal Railroad and Station in Philadelphia," by Joseph M. Wilson, M. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. XXXIV, page 115.

Fig. 25 shows another interesting feature of this station, *viz.*, the endless-chain baggage hoists, worked also by hydraulic power.

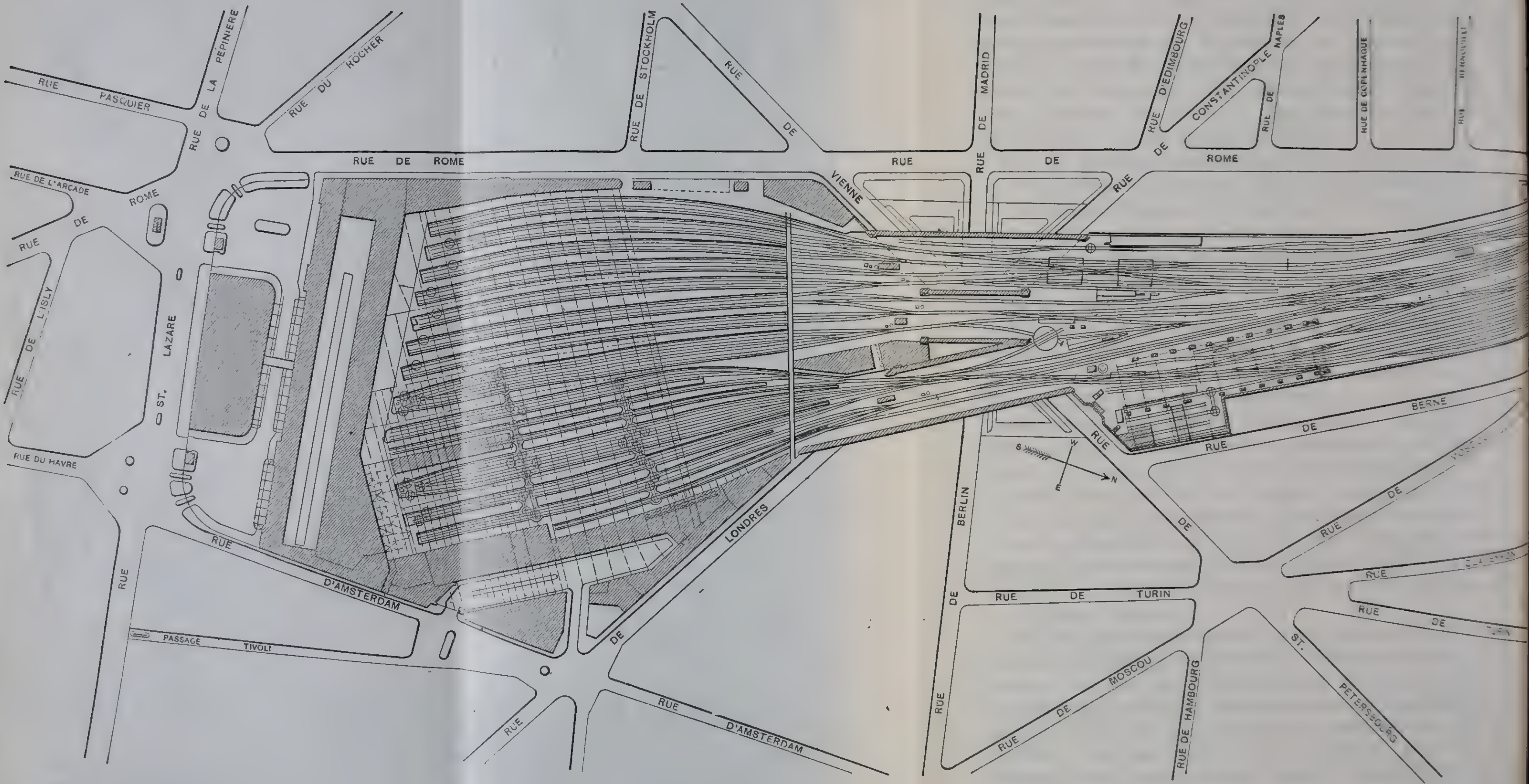
The Central Station, at Antwerp, is another good illustration of the second type. It is of comparatively recent construction, and has a long elevated approach on an embankment, with arched stone bridges over the streets. The details of this station are given in Table 2. There are ten tracks in the station, under a lofty roof with one span. It has a direct approach of two main tracks leading to Brussels, and two diverging from those leading toward Holland. There is a yard with six storage tracks for trains of the busiest morning and evening hours, about 500 m. from the station, and another of ten tracks, 1 500 m. from the station. There is a double ladder crossover between all tracks, immediately outside of the station, and commanded by a complete interlocking system.

Third.—Through Stations at the Street Level.—As an illustration of the third type, the Indianapolis Union Station has been selected. Five proprietary railway companies, in 1888, united their properties, organized a company and built this station. Nine other railway companies were admitted, later, as tenants, with the same privileges as the parent companies.

The main building or head-house is a handsome, imposing and commodious structure, devoted almost exclusively to union station purposes, the lofty main waiting-room in the center occupying a large part of the building. Adjoining, and extending in each direction, is a train-shed, open at each end, for trains coming from each direction. This shed is 200 ft. wide and 700 ft. long, with nine passenger tracks and two freight tracks. The station cost about $1 000 000. The operating expenses during the period of ten years, from 1889 to 1898, inclusive, averaged about $60 000 per annum, or

PLATE LXVIII. VOL. LIV
TRANS. AM. SOC. CIV. ENG.
INTER. ENG. CONG.
CORTHELL ON
RAILROAD TERMINALS

ST. LAZARE STATION, PARIS.



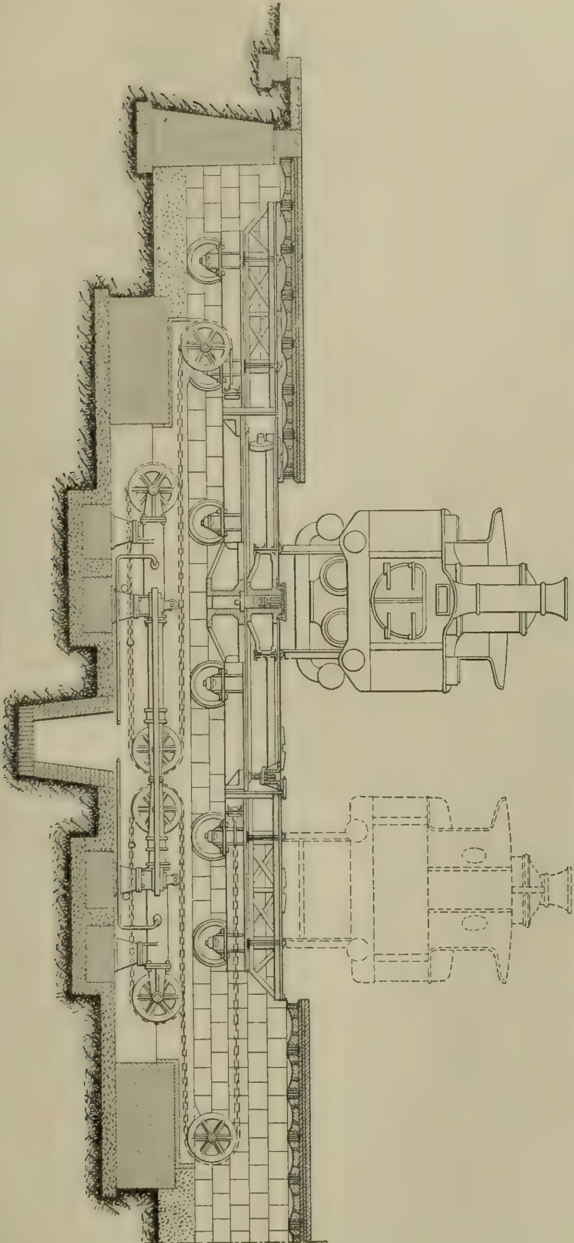


FIG. 24.

TRAVERSE-TURNTABLE OF 5.25 M. FOR LOCOMOTIVES, ST. LAZARE STATION.

23.7 cents per car. The fixed charges averaged about $52 000, or 20.49 cents per car, to which should be added $11 504 for track expenses, or 11.06 cents per car, making a total annual cost of $123 500, or about 55.5 cents per car.

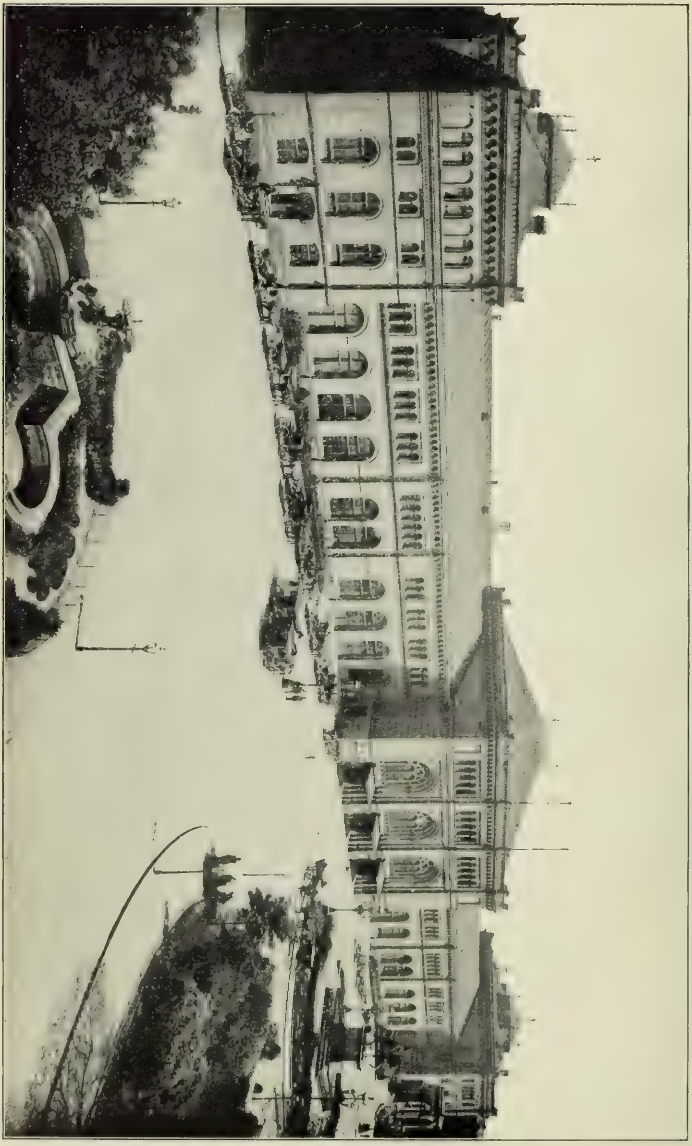
The operation, maintenance, renewals and repairs of a belt railway, also owned by the five companies referred to, and railway and station property, are conducted by a board of managers composed of one representative from each company using the property, under such rules and by such officers and employees as the board prescribes. The President of the Union Railway Company is Chairman of the Board of Managers.

The North Station, Hannover, Germany, is an excellent illustration of Continental through stations at the street level. Hannover is an important city of Central Germany, and is situated on through lines of railway extending from Frankfort to Hamburg and from Bremen and Cologne to Berlin.

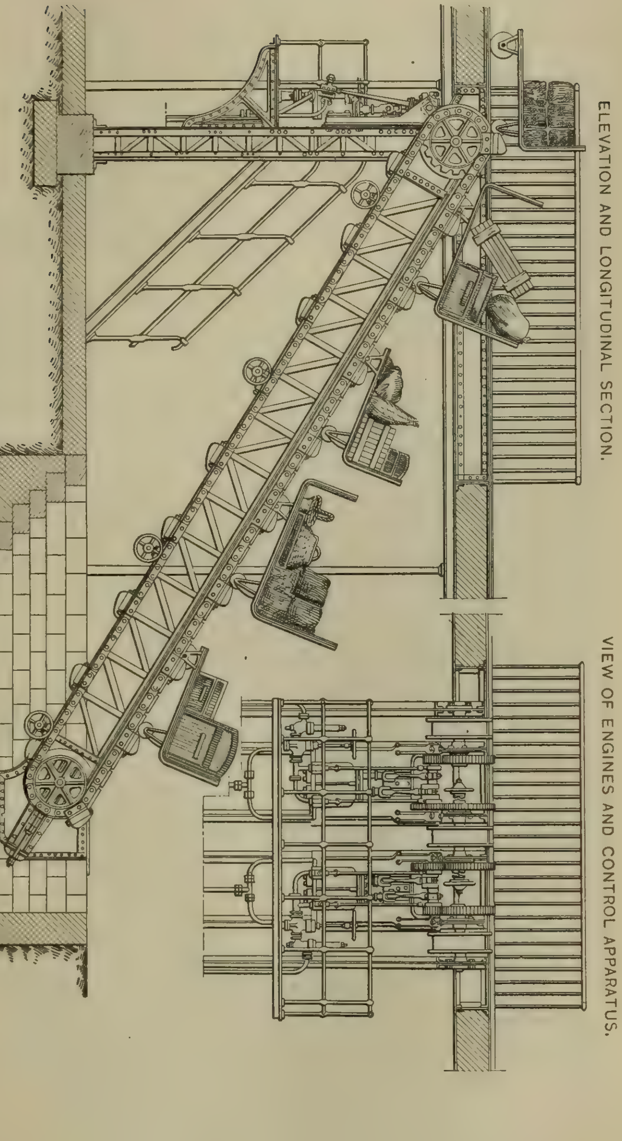
The station is occupied by four important railways. The general plan comprises a commodious head-house, 566 ft. long and 92 ft. wide, and, back of it and attached to it, like the Indianapolis Station, a train-shed, 550 ft. long and 289 ft. wide, with nine tracks. The general layout of the station tracks and approaches is seen in Fig. 26, the character of the head-house, in Plate LXIX, and the train-shed in Fig. 27. The station is furnished with hydraulic and electric power, and appliances for operation. The cost of this station, together with the freight stations, was $5 315 000.

Fourth.—Terminal and Through Stations, Combined.—The new Union Terminal Station, Washington, D. C., now under construction, comes under this type, and it is partly at street level and partly below it. The six railroads entering Washington, two from the north and four from the south, have handled their traffic, thus far, at the two existing stations, separated from each other by a considerable distance, one near Pennsylvania Avenue and Sixth Street, and the other on higher ground, north of the Capitol. To carry out the plans of the National Government, and for the greater convenience of the traveling public, a Union Station has been provided. From the present line of the Philadelphia, Wilmington and Baltimore Railroad, at a point some distance outside the city, an approach will be made passing around the city and uniting with the present approach of the Baltimore and Ohio Railroad, to the intersection of Massa-

PLATE LXIX. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
CORTHELL ON
RAILROAD TERMINALS.



FRONT VIEW, HANNOVER STATION.


ELEVATION AND LONGITUDINAL SECTION.
VIEW OF ENGINES AND CONTROL APPARATUS.

INCLINED BAGGAGE LIFT, ST. LAZARE STATION.

Fig. 25.

chusetts and Delaware Avenues, where the new station is situated. The railroads from the south will reach the new station from over the Potomac River as at present, and then, from Virginia Avenue, by a tunnel with two tracks, passing under First Street, which lies between the Capitol and the Library of Congress, and about 55 ft. below the surface of the street.

These two tracks spread into six when entering the depressed approach to the station, and then into eleven tracks in the station. They are about 16 ft. below the eighteen terminal tracks of the street-level part of the station. There are fifteen platforms on the upper and five on the lower level; five of the upper ones will be used entirely for baggage.

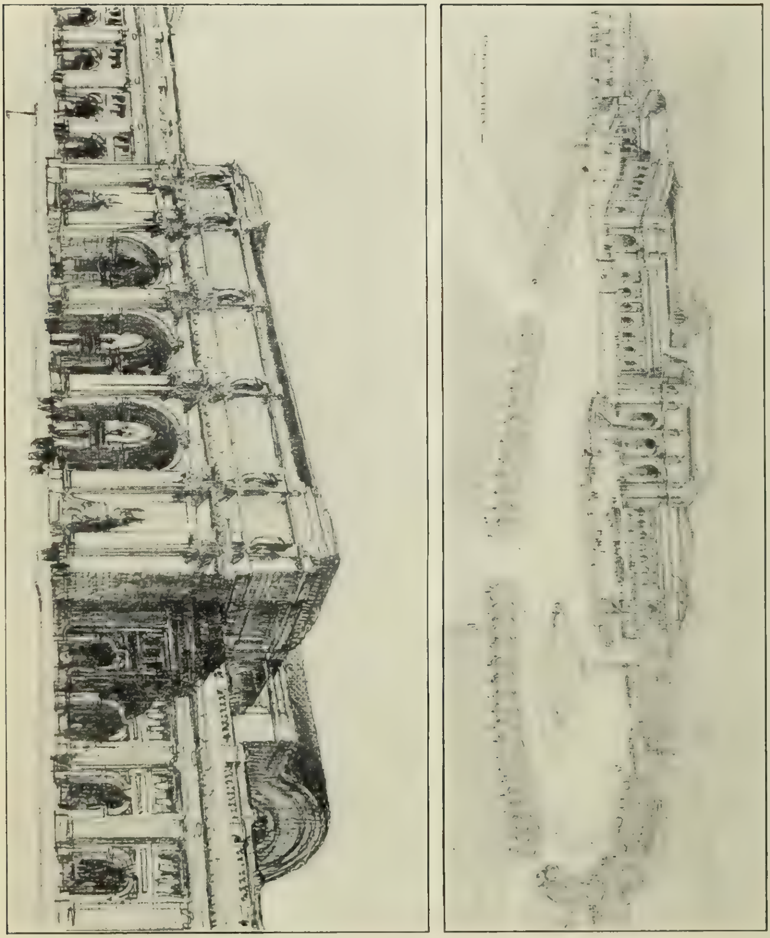
Without going into the details of the station, all of which can be studied from the illustrated descriptions in the *Railroad Gazette* (see references), it is necessary to call attention to certain features which make this monumental station especially interesting.

The General Government participates in the construction of the station by contributing about $4 600 000 toward abolishing the level crossings of railroads and streets, and toward the new plaza, about 500 ft. wide and 1 000 ft. long, in front of the station. The entire cost of the structure and approaches is estimated at $14 000 000.

The station building, proper, is to be about 620 ft. long and from 65 to 120 ft. high, and is to be built of white marble and granite. The three entrance arches are 50 ft. high, and lead into a vaulted, open-air vestibule. The arches at the ends are for carriages, one of which is for Government official use and leads to a suite of apartments for the exclusive use of the President of the United States and the guests of the Nation. The general waiting room is 128 by 236 ft. and 90 ft. high. The concourse, also, is of extraordinary dimensions: 80 by 745 ft., the entire width being 130 ft.—there being 50 ft. on the opposite side of the dividing fence and next to the tracks.

The climate of Washington is mild, and for that reason, and also not to raise an immense and lofty roof near the Capitol, the platforms are covered by "umbrella" sheds, the details of which are shown in Fig. 28. The platforms are generally 900 ft. long and 21 ft. wide. The baggage is handled in the basement, which is almost exclusively devoted to this work. There are four baggage subways: two longitudinal, 16 ft. wide, extending from the main building to

PLATE LXX. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
CORTHELL ON
RAILROAD TERMINALS.



Union Station, Washington, D. C.

PLAN OF TRACKS AT NORTH RAILROAD STATION, HANNOVER.

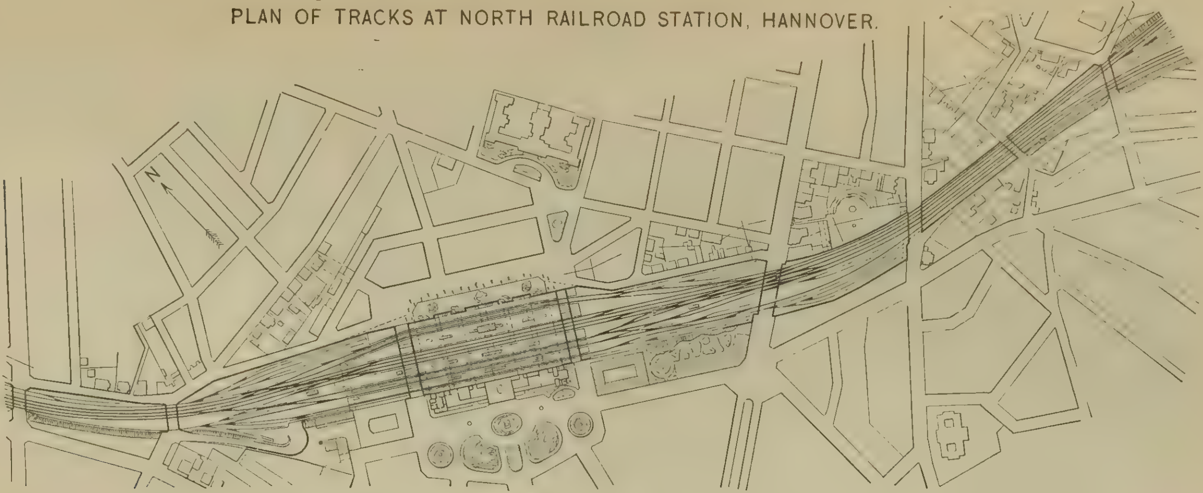
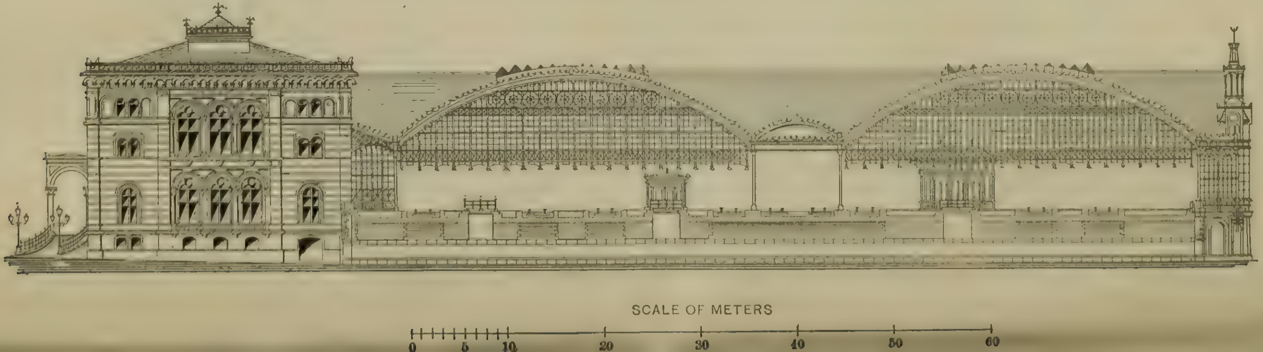


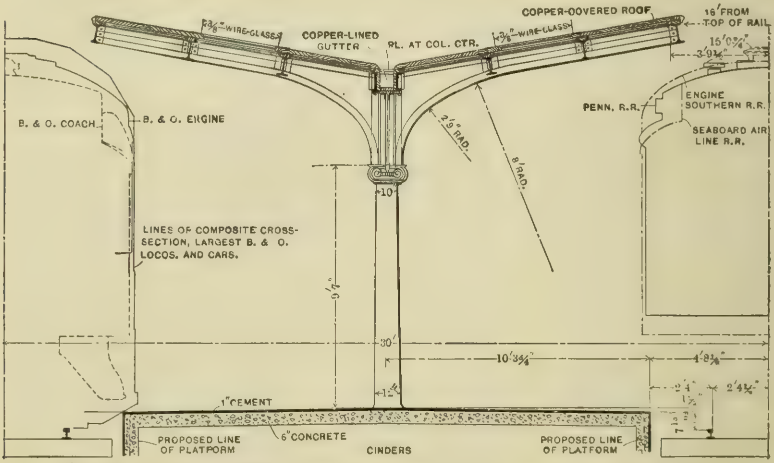
FIG. 26.

SIDE ELEVATION AND SECTION. NORTH RAILROAD STATION, HANNOVER.



the outer end of the platforms above, one transverse, 60 ft. wide, under the tracks at the station end, and one from 20 to 42 ft. wide under the outer end of all the platforms. The express companies' building at the north (approach) end of the station is 420 ft. long and 60 ft. wide, with seven special tracks to serve it.

Some other interesting features are as follows: An invalids' room opening from the concourse; offices of a resident physician; several mortuary chambers not connected with the public use of the station; comfortable dressing-rooms with baths, and a Turkish bath, with swimming pool. There are rooms for one hundred trainmen; also reading-rooms, besides rooms for a branch of the Young Men's Christian Association. The approach from the north is over a masonry viaduct, and there are eight tracks. See Plates LXX and LXXI.



CROSS-SECTION OF UMBRELLA TRAIN-SHED WASHINGTON, D.C., CLEARANCE LINES

FIG. 28.

Another interesting example of the fourth type—depressed and partly through and partly terminal—is Waverley Station, Edinburgh, belonging to and occupied by the North British Railway Company. It cost, including land, $7 500 000. The annual cost of working the station is about $165 000. It has a large passenger traffic, there being about 630 arrivals and departures per day, and 40 in the busiest hour. The general details of the station appear in Table 2. As will

PLATE LXXI. VOL.
TRANS. AM. SOC.
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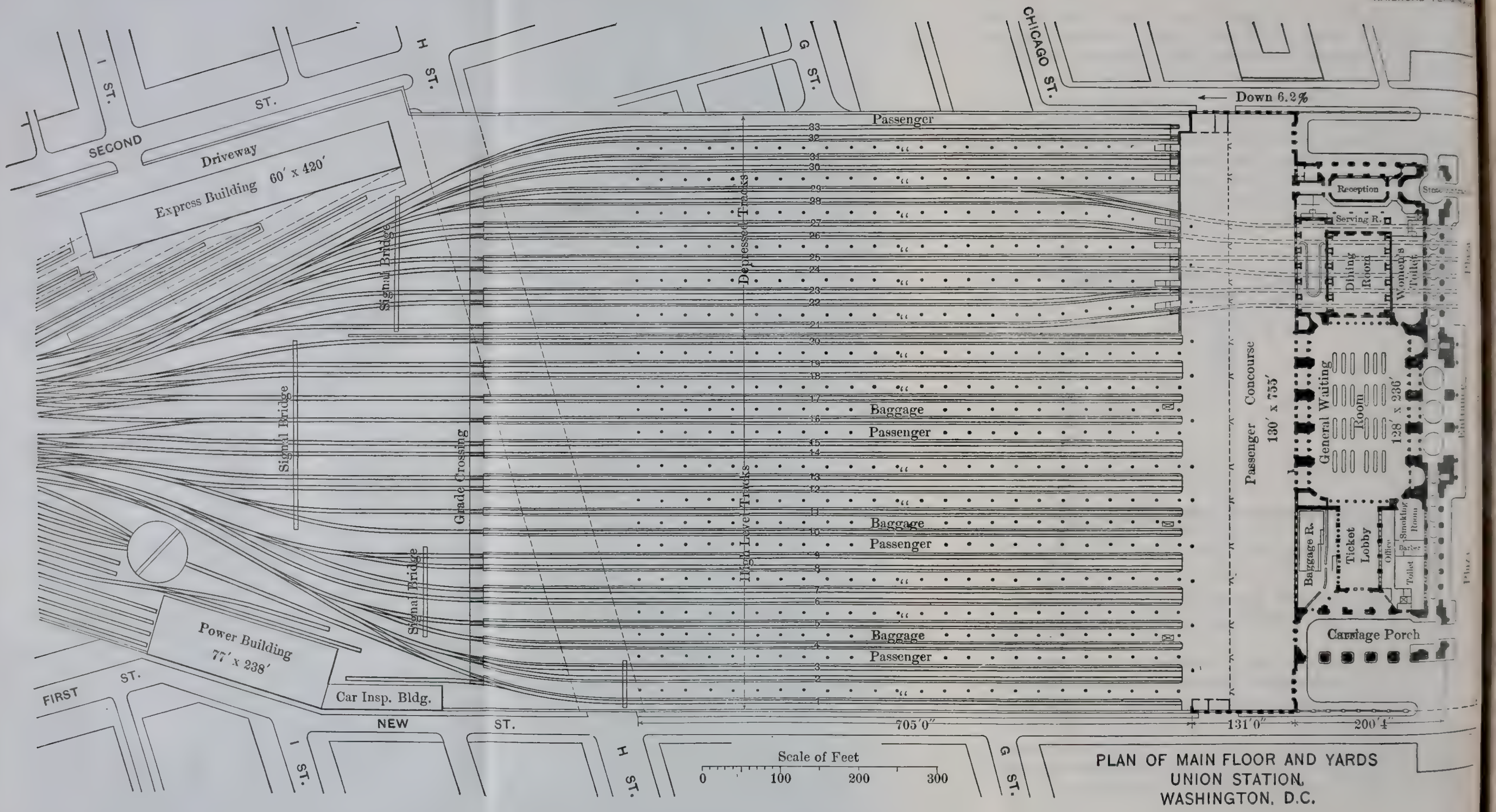
CORTHELL
RAILROAD TERM



PLAN OF MAIN FLOOR AND YARDS
UNION STATION,
WASHINGTON, D.C.

be seen from the plan, Plate LXXII, there are four approach tracks at each end, and both approaches are through tunnels. The grade going south is 1.3% for about 1.25 miles. The north approach is nearly level.

As will be seen by the plan, through trains can pass around the station on either side on two through tracks. There are eight platform, steel tracks on the south and seven on the north. In general physical features the approaches and the station area are somewhat similar to the proposed Pennsylvania Railroad Station in New York City.

There is one other European station which should be given as an illustration of the fourth type, on account of its special features. Reference is made to the Queen Street Station, Glasgow, Scotland, which is a terminal station on the upper or street level, and a through suburban station at the lower level, about 20 ft. below the streets. This station also belongs to the North British Railway Company.

The upper-level station, with ten tracks, is the terminus of the Edinburgh and Glasgow line; the lower-level station, with tunnel approaches and four tracks, is the City and District line passing nearly at right angles to the station tracks above. Table 2 gives the detailed features.

The fourth type is still further illustrated by the beautiful station at Dresden, Germany. It has six terminal tracks at the street level and eight through tracks above. This station, for fine architecture and convenience, cannot be surpassed. The materials of construction are stone, iron and glass, with a profusion of tasteful ornamentation within and without. It has all the numerous and special conveniences of the most modern United States stations. It is brilliantly lighted by electricity everywhere, and is always a model of cleanliness. It has, what is not always found at large stations in the United States, an abundant station service of porters, waiters, etc., in which respect European stations are generally far in advance of stations in America.

There are two waiting-rooms for first- and second- class passengers, and two for third- and fourth- class, with several restaurants. There is a police station, branch post-office, telegraph, telephones, a physician always in attendance, etc., etc. Figs. 1 and 2, Plate LXXIII, illustrate the station.

It is interesting to know something of the character of the approaches to large passenger stations over which so many trains pass daily, and especially during the busiest hour. The information can best be given in a table in which the work to be done and the facilities in the way of approaches are placed side by side. See Table 5.

TABLE 5.—APPROACH TRACKS AND TRAFFIC ON THEM.

Station.	Number of approach tracks.	Number of tracks in station.	Trains in 24 hr.	Trains in 1 hr., maximum.	Ratio between station tracks and approach tracks.	Remarks.
Jersey City, P. R. R.	5	16	281	25	3.2	Terminal.
Reading Terminal, Philadelphia	4	13	417	39	3.2	"
North Union, Boston, Mass	8	23	588	66	2.9	"
Grand Central, New York City	4	18	357	34	4.5	"
South Terminal, Boston, Mass	10	28	861	90	2.8	"
L. S. & R. I. R. R., Chicago, Ill	4	9	182	....	2.2	"
Broad St., Philadelphia	6	16	470	43	2.7	"
St. Louis, Mo	6	30	237	39	5.0	"
Union Depot, Kansas City	4	13	....	....	3.2	Through.
Erie R. R., Jersey City	2	10	....	....	5.0	Terminal.
Central R. R., Jersey City	2	12	....	....	6.0	"
D., L. & W. R. R., Hoboken, N. J	2	10	....	....	5.0	"
West Shore, Weehawken, N. J	2	15	....	....	7.5	"
Liverpool St., London	6	20	1 094	83	3.3	"
Waverley, Edinburgh	4	19	1 101	76	4.7	8 stubs, south. 7 " north. 4 " through.
London Bridge, London	8	25	....	....	3.1	Through.
Waterloo, London	6	18	966	61	3.0	Terminal.
Euston, London	4	13	....	....	3.2	"
St. Pancras, London	3	9	....	....	3.0	"
St. Lazare, Paris	6	31	1 200	74	5.2	"
Dresden, Germany	4 and 6	14	808	49	1.4	From two directions, through and terminal, two direct.
Cologne, Germany	6 and 2	14	300	13	1.8	Terminal and through.
Frankfort, Germany	11	18	478	31	1.6	Terminal.
Hannover, Germany	6 and 4	9	....	....	1.0	6 one end. 4 the other, 4 through.

Table 5 is indicative of the traffic over approach tracks, but it is necessary to know the methods of handling it. All the approach tracks may not be available for the traffic, and the ratio of station

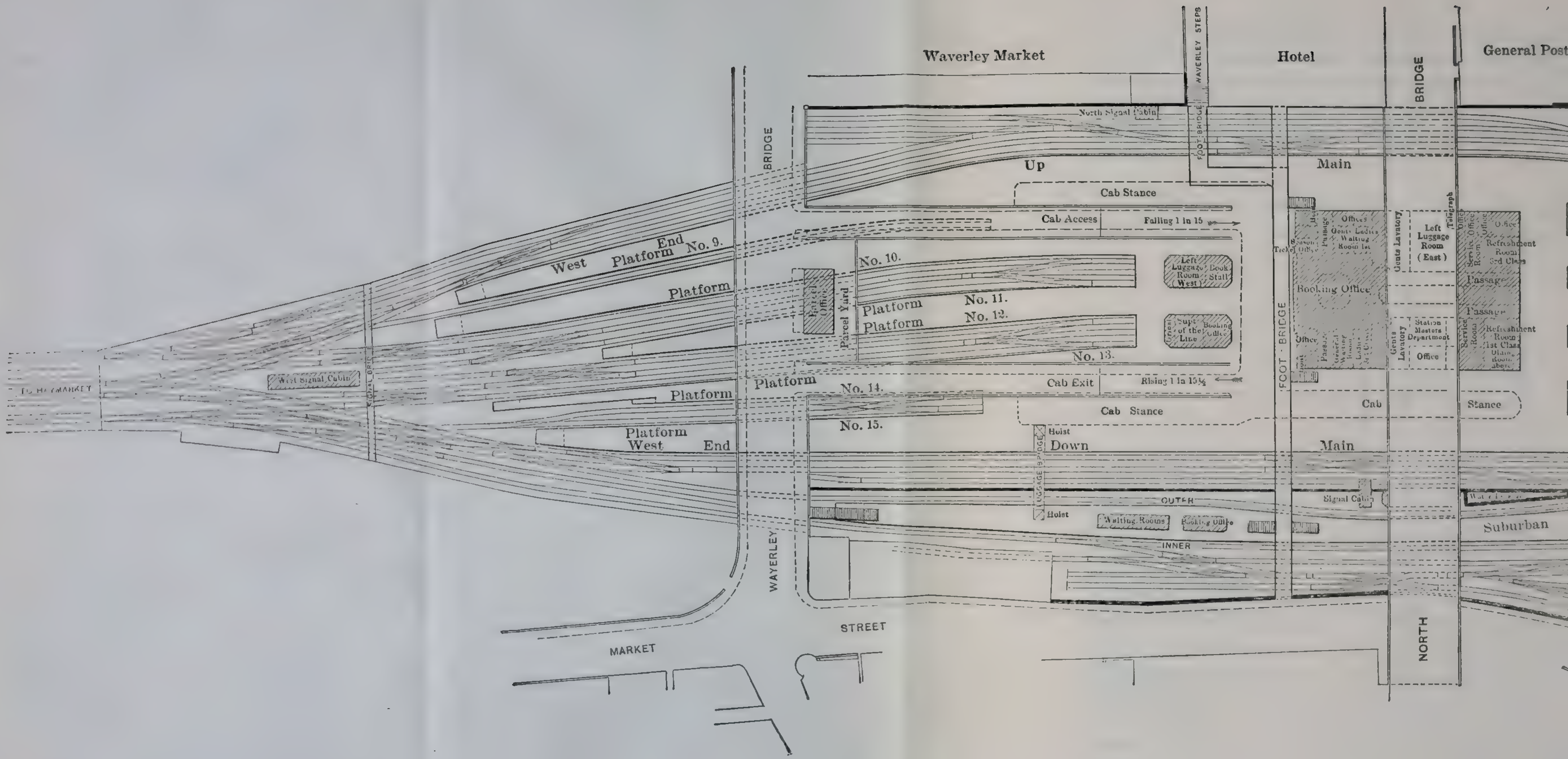
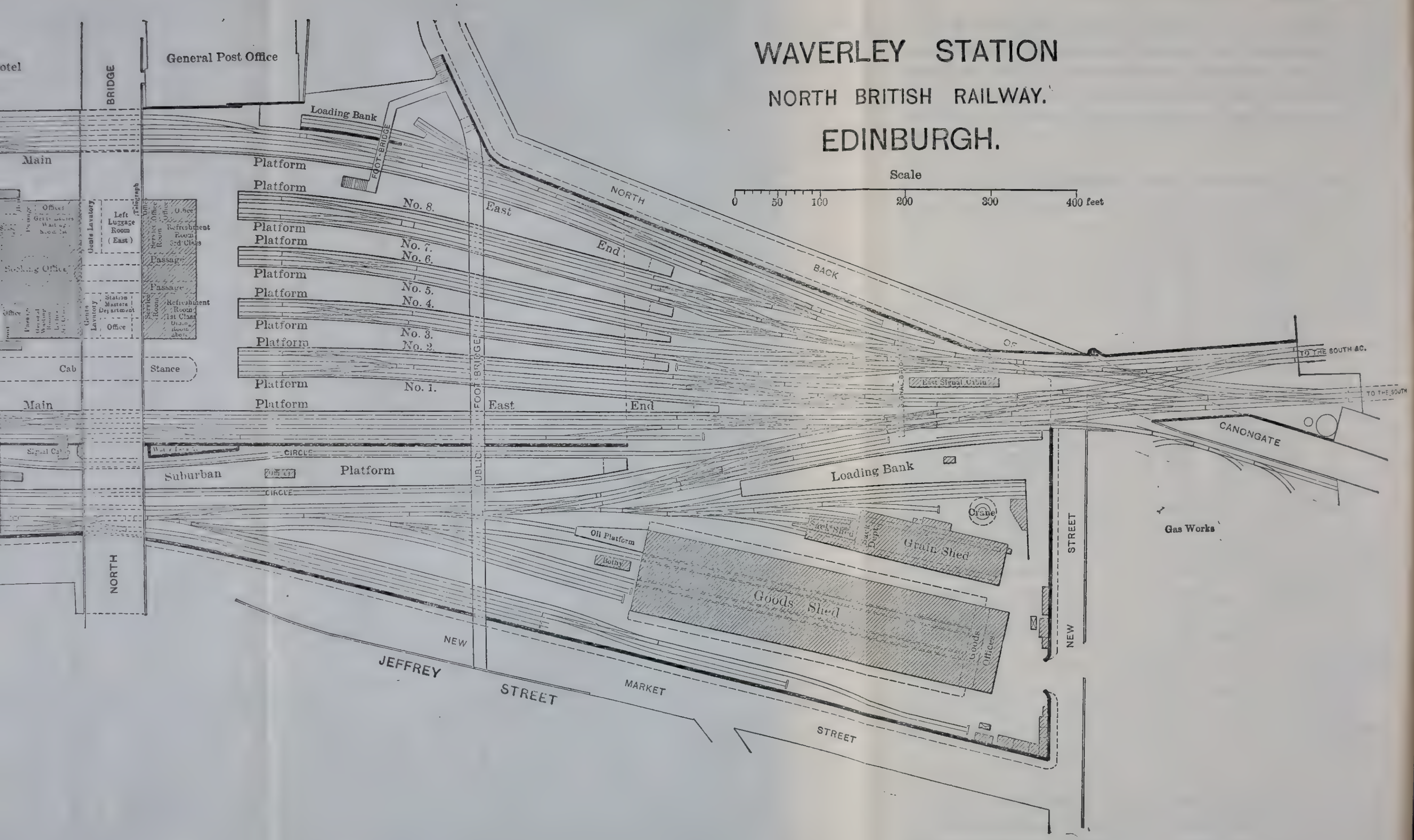

Waverley Market
WAVERLEY STEPS
Hotel
BRIDGE
General Post
North Signal Cabin
FOOT BRIDGE
BRIDGE
Up
Main
Cab Stance
Cab Access
Falling 1 in 15
West End Platform No. 9.
Platform
Parcel Office
Parcel Yard
No. 10.
Left Luggage Room (West)
Book Stall
Platform No. 11.
Platform No. 12.
Supt. of the Line
Booking Office
No. 13.
West Signal Cabin
SIGNAL BRIDGE
To HAYMARKET
Platform
Platform
No. 14.
Cab Exit
Rising 1 in 15½
Cab Stance
No. 15.
Platform West End
Hoist
Down
LUGGAGE BRIDGE
Main
OUTER
Hoist
Waiting Rooms
Booking Office
Signal Cabin
Suburban
INNER
WAVERLEY
MARKET
STREET
NORTH
FOOT · BRIDGE
Season Ticket Office
Passage
Offices
Gents' Ladies' Waiting Room 1st
Booking Office
Office
Passage
General Waiting Room
Ladies 3rd Class
Hoist
Gents Lavatory
Left Luggage Room (East)
Telegraph
Station Masters Department
Office
Gents Lavatory
Office
Service Room
Office
Office
Refreshment Room 3rd Class
Passage
Passage
Service Room
Refreshment Room 1st Class
Dining Room above
Cab
Stance

PLATE LXXII. VOL. LIV. PART F.
TRANS. AM. SOC. CIV. ENGRS.
INTER. ENG. CONG., 1904.
CORTHELL ON
RAILROAD TERMINALS.



WAVERLEY STATION

NORTH BRITISH RAILWAY.

EDINBURGH.

tracks to approach tracks, and of trains as they appear in the table, may be very misleading, if we expect to learn from it just how many movements there are in the busiest hour over each track. One or more tracks, may, for good reasons, be at that time comparatively idle, while another may be absolutely hot with wheels passing over it. The writer is enabled to show the actual number of movements over one of the approach tracks at the Grand Central Station, New York City, on March 21st, 1904. There are four approach tracks, and, by the station time-card, there are in the busiest hour 34 arrivals and departures, or 8.5 trains per track in that hour, according to Table 5.

As stated in Table 5, there are eighteen tracks in the station. This is at Forty-fifth Street; at Forty-ninth Street these tracks converge into four tracks, to enter the approach to the tunnel. They are numbered from east to west. Tracks Nos. 1 and 2 are south-bound (toward the station) to Fifty-fourth Street. (This road runs into the station left-handed, from a point some miles out.) From Fifty-fourth Street south, for a distance of about 1 600 ft. all south-bound traffic is confined to Track No. 2—Track No. 1 being used as a north-bound track for shop trains and engines crossing over to Tracks Nos. 3 and 4 at Fifty-fourth Street. This crossing point is the busiest piece of track on the approach, and, for the hour between 8 and 9 A. M., there are twenty-five scheduled trains and five light engines south-bound, and eight trains and engines north-bound, passing over this stretch of track, or thirty-eight distinct movements in 1 hr., or one in every 1.6 min. This is not an exceptional performance, but daily practice. The information is given for the encouragement of any railway companies contemplating a busy traffic over a small number of tracks.

The foregoing descriptions and illustrations, and the tables and plates, are sufficient to give an idea of the facilities in the United States and in some other countries where large numbers of passengers are handled. The increase of passenger traffic in many large stations has compelled enlargements of facilities. Old stations, which a few years ago were considered ample, are now under reconstruction to avoid either the congestion and inconvenience in the station or its approaches, or to eliminate the dangers of level crossings of railroad tracks or streets.

In Chicago, Ill., the Lake Shore and Michigan Southern Railroad, and the Rock Island and Pacific Railroad, have recently entirely rebuilt their joint station, raising their tracks 15 ft. above the street level.

In Great Britain, the large Caledonian Railway Station in Glasgow, the principal terminal of that road in that city, is being greatly enlarged and improved.

Waterloo Station, London, which by Table 2 is seen to be one of the largest in the world, and with an immense traffic, has been found to be inadequate for its business, and is being wholly rebuilt on a plan entirely different from that of the old station, which, in the course of years, had grown by additions which had destroyed entirely the unity of the original design.

In Paris, in 1900, it was found necessary to bring the Orleans Railway further into the city, and an approach, several miles in length, was built along the bank of the Seine, below the street level, to the Quai d'Orsay, near the Solferino Bridge.

The Western Railroad at the same time was extended across the Seine to the Champs de Mars and thence along the river below the street level to a point in front of the "Hotel des Invalides," where the station called "Gare des Invalides" was built.

The new Gare de Lyons, the great terminal station, in Paris, of the Paris, Lyons and Mediterranean Railway, is approaching completion, and is on a scale far beyond that of the former station; in fact, the old station is entirely done away with.

One of the most important terminal works in the world, now under way, is the reconstruction of the Grand Central Station, New York City.

This station has had successive enlargements, from time to time, in the past, to endeavor to meet the steadily increasing traffic, and it was only three years ago that very extensive interior changes were made, throwing the three waiting-rooms which existed previously, into one large, commodious and elegant room, concourse, etc.; but the traffic has already outgrown these facilities. The company wisely decided to prepare adequately for its business, but, to do this, as no ordinary modifications would meet the requirements, it was decided to raze the present station to the ground and build a new one, and while doing this to make certain other radical changes to

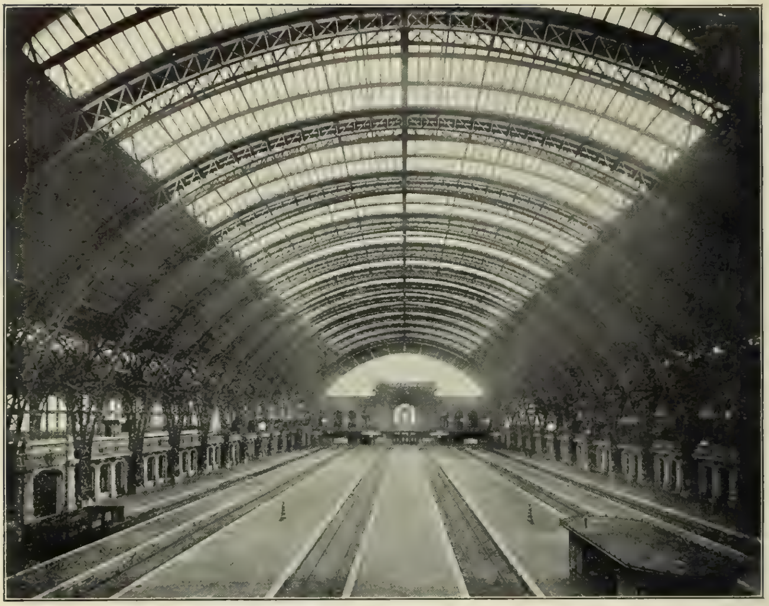


FIG. 1.—MIDDLE HALL, DRESDEN STATION.

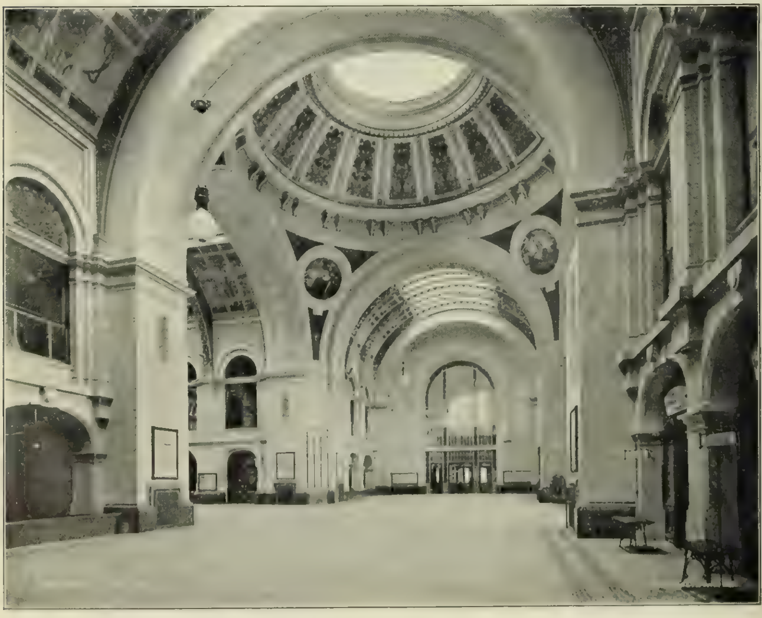


FIG. 2.—HALL, WITH CUPOLA, DRESDEN STATION.

meet new conditions and connections. The plans of the station and other facilities are not sufficiently advanced to present them at the present time.

The writer has endeavored, within the limits of this paper, to give some idea of the large passenger stations of the United States, and of characteristic stations of the same types in Europe and of one in South America—Buenos Aires—in order to make comparisons. He refers again to Table 2, Plates LXIII and LXIV, as the most important part of this paper and as affording the best means for comparing the facilities provided at the twenty-four stations therein detailed.

APPENDIX.

For the further study of the subject, the following references are given:

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Union Terminal, Washington.	*Railroad Gazette,* New York City, December 4th, 1903, and January 15th, 1904.
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Union Station, St. Louis.	"Saint Louis Union Station," by the National Chemigraph Co., St. Louis, Mo. "Proposed Improvements in St. Louis Terminals," by A. P. Greensfelder, M. Engrs.' Club, St. Louis, Mo. *Journal* of the Association of Engineering Societies, Vol. XXXII, No. 1, January, 1904. Also, *Railroad Gazette,* July 24th, 1891.
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L. S. & R. I., Chicago.	*Railroad Gazette,* New York, March 14th, 1902, and July 17th, 1903. *Engineering News,* New York, August 6th, 1903.

Grand Central, Chicago.	*Railway Review,* Chicago, Ill., December 20th, 1890.
St. Lazare, Paris.	*Railway Review,* Chicago, Ill., July 27th, 1889. *Engineering,* London, July 12 *et seq.,* 1889. "Notice sur le Matériel des Modéles et des Dessins, 1889 Exposition."
Broad St. Station, Philadelphia.	*Railroad Gazette,* June 9th, 1893.
Union Depot, St. Paul.	Report on Proposed Improvements, by Henry M. Sperry, June 11th, 1901.
Dresden.	"Preisbewerbung um das Empfangsgebäude des Neuen Hauptbahnhofs in Dresden." Publishers, Von E. A. Seemann, Leipzig, 1893. *Deutsche Bauzeitung,* Vol. XXVI, No. 97, December 3d, 1892.
Cologne.	"Vergleichender Ueberblick über die neueren Umgestaltungen der grösseren preussischen Bahnhöfe." E. Grüttefien. Published by Ernst und Korn, Berlin, 1888.
Frankfort.	An article by E. Grüttefien. Also "Die Hauptbahnhofs-Anlagen in Frankfurt a. M.," by M. H. Megele, and "Das Empfangsgebäude des Hauptbahnhofs," M. H. Eggert. Published by Wilhelm Ernst & Sohn, Berlin, 1892.

TRANSACTIONS
AMERICAN SOCIETY OF CIVIL ENGINEERS.

INTERNATIONAL ENGINEERING CONGRESS,

1904.

DISCUSSION ON
RAILROAD TERMINALS.

By Messrs. Albert P. Greensfelder, Wilkie Woodard, George W. Parsons, E. E. R. Tratman, S. G. Homfray, W. M. Camp, Robert Moore, Charles L. Morgan and Elmer L. Corthell.

Mr. Greensfelder.

Albert P. Greensfelder, Jun. Am. Soc. C. E., St. Louis, Mo.—The speaker has examined with much interest the many features of large station design brought out for comparison in Mr. Corthell's paper, and realizes the immense amount of labor necessary to gather and arrange the data in such shape as to make the investigations valuable. The tabular compilation presents such information clearly, and, in addition, Mr. Corthell has defined very plainly some important features of passenger terminals.

During the recent reconstruction of the St. Louis Union Station, the speaker, as Assistant Engineer of the St. Louis Terminal Railroad Association, devoted considerable study to various problems incident to large station design. This work was in progress for eighteen months, under the direction of Daniel Breck, Chief Engineer, and J. L. Armstrong, Engineer of Maintenance-of-Way, and was completed in May, 1904.

The St. Louis Union Station when opened, September 1st, 1894, was considered sufficiently large to handle all traffic for twenty-five years at least. Two years ago, however, it became evident that material alterations would be necessary to meet existing conditions. Accordingly, many changes throughout the head-house, train-shed, approach tracks and yards were made, to provide facilities for the

Mr. Greensfelder. heavy St. Louis World's Fair traffic, as well as the regularly increasing business.

Thinking that it may be of some interest to compare the points brought out in the original design, when there was no precedent to follow, with those features where enlargement or changes have been shown to be necessary by ten years' experience, the speaker submits Tables 6 and 7 (of special and general information) which indicate the extent of the facilities in the St. Louis Station before and after this reconstruction.

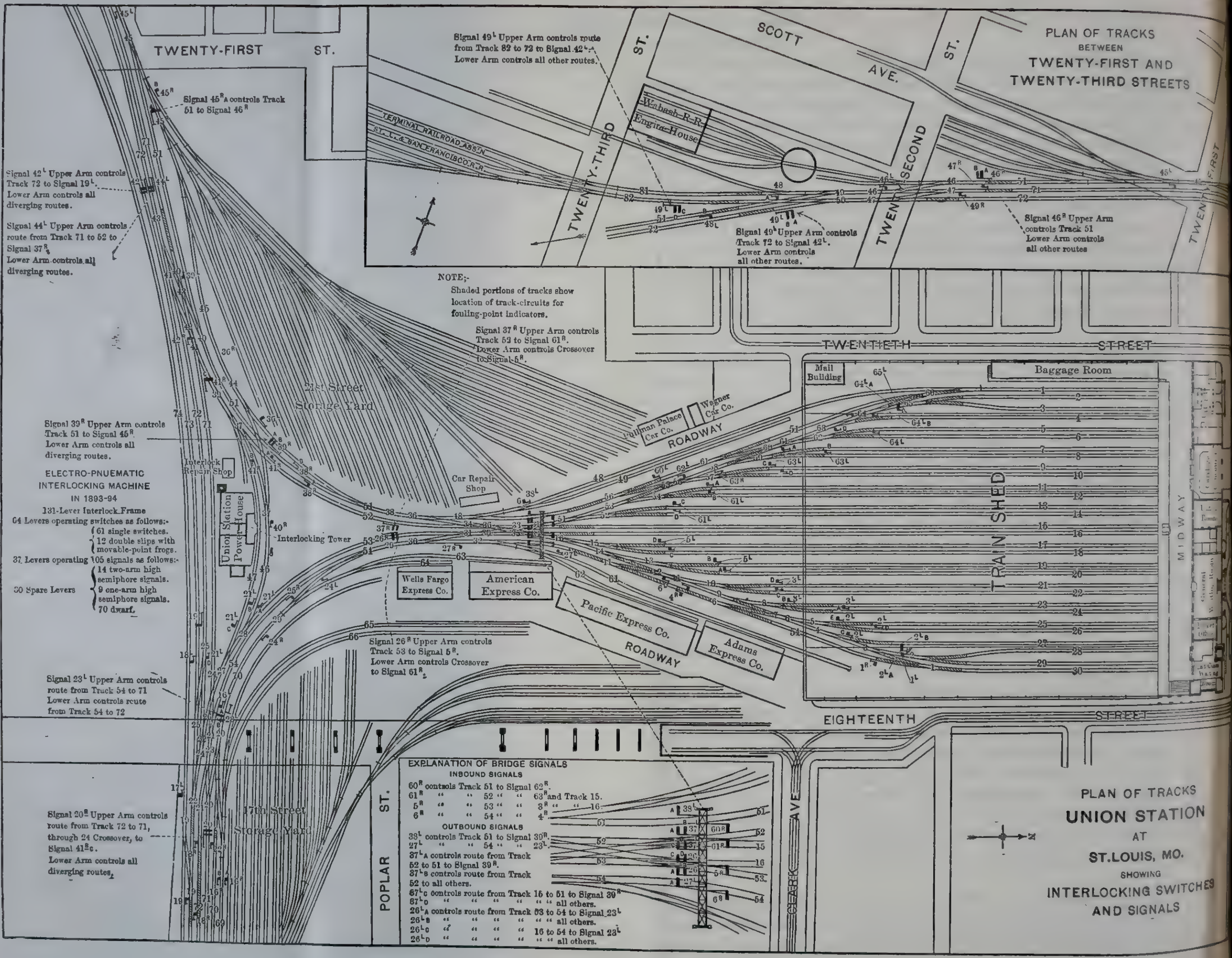
In order to make these tables as convenient as possible, the items in Table 6 have been given the same numbers as the column headings of Mr. Corthell's Table 2, and some additions and corrections have been made. Table 7 is a comparison of special items relating to the station. Plate LXXIV is a plan of the old general arrangement, and may be compared with the plan of the new arrangement shown by Mr. Corthell's Figs. 22 and 23.

In planning rearrangements, it is evidently impracticable to design with a free hand, consequently, it has been necessary to adapt the requisite improvements to existing conditions, and fit them into the general design as far as possible. Another important consideration entering into such work is the necessity of providing accommodation for the heavy daily traffic, without interruption or serious delay during the construction period. Taking into account, therefore, the inability to secure the desired legislation and areas for track rearrangement, baggage and express facilities and coach storage yards, as well as lack of head-house space for the proper enlargement of interior accommodations, the following may be cited as the principal improvements: Increase in number of approach tracks; track rearrangements permitting increased number of simultaneous train movements; yard changes requiring less switching; increased interlocking control for rapid handling of trains; increased express-house and yard area; increased baggage-platform space; building of large subway system for the handling of baggage, mail and express; the extension of the train-shed to accommodate longer trains; the widening of the concourse for the midway, and the adoption of the double-gate system; pneumatic-tube system for the transmission of baggage checks; the transmission of information regarding train movements by telautograph; and the increase in ticket-selling space, parcel-rooms, waiting-rooms, lunch-rooms and lavatory, by the elimination of the carriage concourse and smoking-rooms, and a decrease in the size of the second-class waiting-room.

Independent stations, while evidently more popular with city merchants deriving profit from lay-over passengers, are not as convenient for railroad purposes or for through passengers as union

ireens-
lder.

PLATE LXXIV. VOL. LIV,
TRANS. AM. SOC. CIV.
INTER. ENG. CONG.,
GREENSFELDER ON
RAILROAD TERMINA



PLAN OF TRACKS
UNION STATION
AT
ST.LOUIS, MO.
SHOWING
INTERLOCKING SWITCHES
AND SIGNALS

PLAN OF TRACKS
BETWEEN
TWENTY-FIRST AND
TWENTY-THIRD STREETS

Signal 49^{L} Upper Arm controls route from Track 82 to 72 to Signal 42^{L}. Lower Arm controls all other routes.

Signal 49^{L} Upper Arm controls Track 72 to Signal 42^{L}. Lower Arm controls all other routes.

Signal 46^{R} Upper Arm controls Track 51 Lower Arm controls all other routes

Signal 45^{R}A controls Track 51 to Signal 46^{R}

Signal 42^{L} Upper Arm controls Track 72 to Signal 19^{L}. Lower Arm controls all diverging routes.

Signal 44^{L} Upper Arm controls route from Track 71 to 52 to Signal 37^{R}. Lower Arm controls all diverging routes.

NOTE;-
Shaded portions of tracks show location of track-circuits for fouling-point indicators.

Signal 37^{R} Upper Arm controls Track 53 to Signal 61^{R}. Lower Arm controls Crossover to Signal 5^{R}.

Signal 39^{R} Upper Arm controls Track 51 to Signal 45^{R}. Lower Arm controls all diverging routes.

ELECTRO-PNUEMATIC
INTERLOCKING MACHINE
IN 1893-94

131-Lever Interlock Frame
64 Levers operating switches as follows:-
- 61 single switches.
- 12 double slips with movable-point frogs.

37 Levers operating 105 signals as follows:-
- 14 two-arm high semiphore signals.
- 9 one-arm high semiphore signals.
- 70 dwarf.

30 Spare Levers

Signal 26^{R} Upper Arm controls Track 53 to Signal 5^{R}. Lower Arm controls Crossover to Signal 61^{R}.

Signal 23^{L} Upper Arm controls route from Track 54 to 71 Lower Arm controls route from Track 54 to 72

Signal 20^{R} Upper Arm controls route from Track 72 to 71, through 24 Crossover, to Signal 41^{R}c. Lower Arm controls all diverging routes.

EXPLANATION OF BRIDGE SIGNALS

INBOUND SIGNALS

60^{R} controls Track 51 to Signal 62^{R}.
61^{R} " " 52 " " 63^{R} and Track 15.
5^{R} " " 53 " " 3^{R} " " 16.
6^{R} " " 54 " " 4^{R}.

OUTBOUND SIGNALS

38^{L} controls Track 51 to Signal 39^{R}.
27^{L} " " 54 " " 23^{L}.
37^{L}A controls route from Track 52 to 51 to Signal 39^{R}.
37^{L}B controls route from Track 52 to all others.
67^{L}C controls route from Track 16 to 51 to Signal 39^{R}
67^{L}D " " " " " " all others.
26^{L}A controls route from Track 53 to 54 to Signal 23^{L}
26^{L}B " " " " " " all others.
26^{L}C " " " " 16 to 54 to Signal 23^{L}
26^{L}D " " " " " " all others.

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stations which permit close connections between trains of all roads, and which do not lose *en route* the advantages gained by the high speeds demanded on limited trains.

Properly designed union stations, where the amount of business handled should diminish the unit cost, while the fixed charges should also be decreased, as one large station eliminates the duplication of track and structure, should be more economical, from an operating standpoint. In this, however, one must consider the location of the single station, the room for future enlargement, and the necessary expense to be borne by the railroads in order to reach such a station.

It is impossible to design a large station so that all departments will be exactly in correct proportion to its traffic, but a careful study of Mr. Corthell's paper should aid considerably in future planning. The application of such information, however, is the more vital task, as correct interpretation, to suit local and special conditions, is essential. Not only must present conditions be met, but provision for the future must be made, and who can foresee what changes in kind or amount of business will take place? It is thus evident that refinements in such determinations are out of place, and, after a proper study, there is nothing but the engineer's good judgment to govern in each case.

Irrespective of local conditions, there are, of course, a number of general principles which hold, and the speaker has in mind a few which might come up for consideration. A station takes care of four kinds of traffic, *viz.*, trains, passengers, trucks and wagons; and the elimination of surface crossings, or conflict of any of these kinds of traffic with one another, will tend materially to prevent congestion. The recent tendency toward handling baggage in subways below the tracks is an important step in this direction, but both underground and overhead construction in the train-shed and head-house would often insure a better separation of business, and render close connection between trains more positive and rapid.

The facility with which traffic of any kind is handled depends upon each of five factors:

First, the size of the conveying unit, or its capacity;

Second, the number of such units;

Third, the rapidity with which the units can be handled;

Fourth, the period of time in which the business must be handled;

Fifth, the necessary space in which to handle it.

Increased passenger traffic severely taxes the capacities of the present stations, as the train which formerly averaged 6 to 8 coaches now carries 10 and 12. These longer and heavier trains require more time in which to stop and start under signal, and are thus less

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quickly handled, particularly if hampered by curvature or adverse gradients. The additional train lengths need longer shed tracks, and the continual growth of large cities, with their increasing suburban and through travel, demands a greater number of such trains. Operating departments, however, are troubled mostly by the large percentage of the total daily business which must be handled in one- or two-hour periods. It is this last question, of handling intermittently large volumes of traffic at short intervals, which most often determines the size of the stations, and presents to the engineer the economic factor as to how much expenditure is justifiable for valuable real estate, trackage and structure.

The provision of proper facilities for efficient handling of the thousands of people who daily pass through the modern stations of the larger cities, taxes the ingenuity of both the architect and the engineer. Too often, these facilities have not been given the proper consideration, and the size and arrangement of the station have been considered secondary to architectural design. Nothing is more beautiful or satisfactory than a large station tastefully arranged and artistically embellished, but the æsthetic must not govern at a sacrifice to the practical.

People tend to move in the direction of least resistance, and stairways and narrow passages are not conducive to their rapid movement. The attempt, at all large stations, to separate suburban from through passengers, helps to prevent congestion, as does the division of in-bound and out-bound traffic, where local urban facilities permit such distribution. By careful study, it is often possible, also, to separate those who have purchased tickets from those who have not; those wishing to use the waiting and lunch-rooms, and those seeking direct access to trains; passengers waiting to take an incoming train and those who anticipate the arrival of friends or relatives on that train.

While it is impossible to separate traffic of every kind, it is noticeable that a few signs properly placed in prominent view will direct and divide the masses. Sufficient counter space, for selling tickets, handling parcels, delivering hand-baggage, checking trunks, and in lunch-rooms, is essential for the rapid handling of many people. Specialization of operators and clerks, in selling tickets and checking baggage, by concentrating their attention on certain railroads or divisions, and attracting to them, by posted notices, the passengers desiring services from those roads, enables these attendants, by saving their steps and quickening their capacities, to serve greater numbers. Although American people adapt themselves very rapidly to new conditions, the individual passenger is apt to become confused in quickly moving crowds, and it is quite a task for him to get his bearings in a strange station. People thus at a loss as to what

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to do or where to go tend to block traffic by standing still, or delay their presence in the station by tracing and retracing their steps in an endeavor to transact their business. This tendency in one person or group is unnoticeable, of course, but, multiplied manifold, it presents quite a problem, and is worthy of consideration. Bureaus of information, bulletin boards prominently displayed, with train movements posted in large letters, automatically by telautograph, or manually, and track signs bearing the name, color, or insignia of the railroad, and the principal stations at which trains stop, aid materially in directing these crowds.

The adoption of a system for checking baggage at some convenient point in the head-house, and transmitting the trunk checks by pneumatic tubes to the baggage storehouse has proven very successful at the St. Louis Station. This enables the serving of the passenger at an accessible point, and, by not requiring the baggage-rooms to be within convenient walking distance, permits of their location where space is not so valuable or trucking distances so great.

The handling of baggage, mail and express matter is a source of considerable trouble, particularly in the majority of stations where trains heading in require people to pass the forward cars. At present, the usual method of handling this kind of business is by hand-drawn trucks, loading and unloading the cars as they stand under the shed. Although subways eliminate grade crossing by these trucks and trains, and separate platforms between trains prevent inconvenience of passengers, there is considerable room for improvement, both from an economic standpoint and as regards rapidity of service. Heavily laden hand-trucks could give way to operation by electricity, air, or some system of telpherage, permitting greater rapidity of movement and increase in capacity of units.

Arrangements should provide for the loading of baggage, express, mail, theatrical or milk cars outside the shed wherever possible, and also for their connection to the trains in the shed a few moments before leaving time, in order to secure the advantage of bulk movement. In large towns, it is becoming the practice to connect the main post-office with a sub-office at the station by pneumatic tubes, for the more speedy handling of mail and in order to permit of later collections in the city before train departure. The mail, in bags, from this sub-office is usually carried to the cars on trucks, but it might not be impracticable to extend the tube system directly to the tracks, and, by having a central station at some convenient point, distribute the mail direct to the car.

Careful provision for omnibus and wagon space must be made, since wagon access to cars in a head-end team yard enables direct transfer of head-end matter, and minimizes the necessary trucking.

Aside from the head-house and train-shed, station design is in-

Mr. Greensfelder. complete without the proper approach tracks and yard space. Track arrangements, in avoiding train congestion at narrow throats, should yet provide the requisite connections for direct switching, and necessitate the fewest possible movements within station limits. Interlocking which permits short rapid switching is as desirable as provision for through movements; and distant signals, indicative of clear routing, in order to facilitate movements through the yards, are not out of place, if the curvature and grades permit such speed. Track crossings which cannot be eliminated or spanned in the yard district should be scattered, in order to avoid congestion or conflicting traffic at any one point. Adequate coach-yard facilities are essential for the proper handling of trains, and insufficient trackage, not properly equipped with steam, air, water and electricity for car service, too often limits station capacities.

Extreme gradient in either direction on train-shed tracks or station leads is certainly to be avoided if possible, for heavy trains of coaches and sleepers suddenly stopped by signal are but slowly started, even by large engines, and considerable trouble is experienced when stalled trains block a busy station. The movement of out-bound trains, starting on scheduled time under a director's orders, being perhaps more easily governed in the yard than that of in-bound trains subject to exterior delays, any preference in the direction of grades might, perhaps, favor the latter, enabling their rapid handling to prevent congestion. The desirability of switching passenger cars over interlocking plants by gravity is questionable, but a down grade toward bumping posts avoids the danger of cars under a shed starting by themselves and fouling the leads. It might be said, however, that a small up grade on shed-tracks is not undesirable as a braking aid to destructible bumping posts, as it often prevents damage to property and persons in the midway beyond.

The question of curvature involves the consideration of engine wheel-base, latitude in movement of Pullman car vestibules and couplers, and the coupling of broken passenger trains. It is hardly practicable to couple two 80-ft. sleepers on a curvature greater than 10°, and No. 7 frogs on 15° curves should not be exceeded where road engines with long wheel-bases are used. It is very desirable that track arrangements should embody the use of frogs not less than No. 9, with their supplementary 9° curvature.

The double midway system, as built at the St. Louis Union Station, consists of two fences, 50 ft. apart, with gates in each fence opposite each track platform. It was designed for the purpose of caring for the enormous crowds expected during the Louisiana Purchase Exposition, and served the purpose of separating the passengers going to trains from those waiting at the station, or who

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accompany arriving or departing friends. Experience has demonstrated that those of the latter class, by gathering around the gates of the single midway, prevent ready access for passengers hurrying to their trains. The operation of the double system, in permitting passengers for any train to pass through all gates of the front midway into the second enclosure, eliminated that congestion. Besides, by only allowing passengers with tickets into such area, the second midway becomes essentially a working space, enabling rapid movement of passengers from midway to train, or train to train, as the case may be. It has saved many from missing connections on crowded occasions, and, with gates leading directly from the street into the second midway, can accelerate the handling of regular passengers having suburban or commutation tickets, by keeping them separated from the waiting throngs. The number of additional gatemen required to attend the gates in the two fences varies with the number of people and the frequency of trains, and, during certain portions of the day when traffic is light, it is necessary to man only a portion of one line of gates. Where barrier frontage and increased gate width are necessary, the double midway system should be successful.

It is not essential that the train signs be seen from the first midway, as all passengers with tickets are admitted through any gate into the second midway, from which place they can seek the gate leading to their respective trains. The arrangement of signs is often a station master's preference, but they can be readily placed to suit any convenience deemed advisable.

Due to reconstruction work during the first half of 1904, and also to the unusual traffic of the Louisiana Purchase Exposition, any figures as to the costs of maintenance and operation of trains at the St. Louis Station obtained at this time would not be comparable with costs at other stations, nor would they be indicative of costs under normal conditions.

The Grand Hall, or large waiting-room, on the second floor of the St. Louis Union Station was, until a few years ago, reached only from the street or by a stairway from the general waiting-room directly below. The architect's original plan for the station provided for a stairway to this hall from the outside midway as well, but, for some reason, the stairway was not built. People, therefore, sought this hall but little, and, seemingly unaware of its presence, overcrowded the room below.

Several years ago, a large areaway was cut out of the floor to increase the ventilation of the room below, and by presenting the upper room to the view of the people, an endeavor was made to get them to use it. This met with only partial success, and, recently, a stairway leading directly into the midway has been built, that part

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Baggage building	24	300 × 30 ft., 2 stories. Second story used for baggage, storage and offices.	300 × 30 ft., 2 stories. Second story used for baggage, storage and offices.
Express buildings	25	4 buildings for 6 companies: 150 × 50 ft.; 250 × 50 ft ; 150 × 50 ft. and 100 × 50 ft. = 32 500 sq. ft. (1 or 2 stories).	5 buildings for 6 companies. 196 × 67 ft.; 206 × 61 ft.; 149 × 70 ft.; 118 × 61 ft., and 170 × 43 ft. = 50 710 sq. ft. (3 or 4 stories).
Postal building	26	70 × 40 ft. = 2 800 sq. ft. (2 stories).	229 × 43 ft. = 9 847 sq. ft. (4 stories).
Railroad offices	27	General offices of Terminal Co. in Head-house above.	General offices of Terminal Co. in Head-house above.
Other rooms in Head-house	28	Telegraph = 3 870 sq. ft. Pullman ticket office. Confectionery = 638 sq. ft.	Telegraph = 3 870 sq. ft. Pullman ticket office, 20 × 16 ft. Baggage checking = 638 sq. ft.
Train-Shed:			
Tickets examined, where	29	From Midway to track platforms, through one set of gates.	From Midway to track platforms, through one or two sets of gates.
General dimensions	30	601 × 630 ft. = 378 630 sq. ft. 606 × 70 ft. = 42 420 sq. ft.	601 × 810 ft. = 486 810 sq. ft. 606 × 70 ft. = 42 420 sq. ft.
Arches	31	1 of 141 ft., 2 of 139 ft. and 2 of 91 ft.	1 of 141 ft., 2 of 139 ft. and 2 of 91 ft.
Midway	32	606 × 50 ft. = 30 300 sq. ft.	606 × 70 ft. = 42 420 sq. ft. permanent. 601 × 50 ft = 30 050 sq. ft. temporary.
Head platform	33	20 ft. wide × 606 ft. = 12 120 sq. ft.	10 ft. wide × 601 ft. = 6 010 sq. ft.
Number of tracks	34	32.	32.
Track length	35	350 to 1 085 ft. Total = 20 130 ft.	770 to 950 ft. Total = 27 400 ft.
Platforms: Passenger	36	17 of 13 to 17 ft. × 630 ft.	17 of 13 to 17 ft. × 750 ft.
Baggage	37	1 of 40 × 260 ft.	1 of 40 × 510 ft.
Lifts: Passenger	38	None.	None.
Baggage	39	None.	37 lifts, 5 × 19 ft., for baggage, mail and express.
Subways	40	None.	Baggage, mail and express. 1 Main, 601 × 120 ft. 5 Branch. Total = 103 000 sq. ft.
Overhead passages	41	None.	2 17-ft. foot bridges over Midway, with stairs to track platforms and Midway.
Other features and total	42	Station Master's office, 10 × 12 ft. Conductors' " 19 × 12 ft.	Station Master's office, 29 × 12 ft. Conductors' " 21 × 11 ft. Hand-Baggage Room, 50 × 34 ft.
Approach: Maximum grades	43	0.50% for 1 500 ft.	0.75% for 1 000 ft.
Maximum curves	44	460 ft. radius, 500 ft. long. No. 7 switches.	430 ft. radius, 500 ft. long. No. 7 switches.
Hotel	45	118 rooms.	118 rooms.
Trains: Number daily	50	224 (on January 11th, 1902).	468 (on July 15th, 1904).
Number in busiest hour	51	37 (7 to 8 A. M.).	49 (7 to 8 A. M.).
Normal length of longest trains	52	486 ft.	530 ft.

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TABLE 6.—Comparison of Facilities at St. Louis Union Station, Before and After Reconstruction (September 30th, 1904).

General Information.

Items Compared.	No. of Item.	Before Reconstruction.	After Reconstruction.
City	1	St. Louis.	St. Louis.
Name of Station	2	Union Station.	Union Station.
Date opened	3	Sept. 1, 1894.	May 1, 1904.
Ownership: Owned by	4	Terminal Railroad Association.	Terminal Railroad Association.
Number of occupants	5	20 companies.	23 companies.
Elevation: Below street level	6	15 ft. below street level at east end.	15 ft. below street level at east end.
At street level	7	At street level at west end.	At street level at west end.
Head-house and Main Station Buildings-			
General dimensions	8	606 × 80 ft. — 48 480 sq. ft.	606 × 80 ft. — 48 480 sq. ft.
General waiting-room	9	75 × 119 × 16 ft. = 8 925 sq. ft. Grand Hall, 74.5 × 119 × 60 ft. — 8 865 sq. ft. Second-class, 77.6 × 39 × 16 ft. — 3 026 sq. ft. and 77.6 × 20 × 16 ft. — 1 552 sq. ft.	75 × 119 × 16 ft. = 8 925 sq. ft. Grand Hall, 74.5 × 119 × 60 ft. = 8 865 sq. ft. Second class, 77.6 × 39 × 16 ft. = 3 026 sq. ft.
Women's special waiting-room	10	54.5 × 73 × 15.75 ft. — 3 978 sq. ft. 56 × 75 × 15.75 ft. = 4 200 sq. ft., retiring-room.	54.5 × 73 × 15.75 ft. = 3 978 sq. ft. 56 × 75 × 15.75 ft. = 4 200 sq. ft., retiring-room.
Men's special waiting-room	11	71 × 55.5 × 15.75 ft. — 3 940 sq. ft.	None.
Women's toilet-rooms	12	69 × 18 × 15.75 ft. = 1 242 sq. ft. 20 × 19 × 17 ft. = 380 sq. ft., second class.	69 × 18 × 15.75 ft. = 1 242 sq. ft. 20 × 19 × 17 ft. = 380 sq. ft., second class.
Men's toilet-rooms	13	36 × 23 × 17 ft. — 828 sq. ft. 20 × 18.5 × 17 ft. = 370 sq. ft., second class.	82 × 71 ft. = 5 822 sq. ft. 82 × 71 ft. = 5 822 sq. ft., second class.
Bath rooms	14	In hotel and ladies' toilet.	In hotel and ladies' toilet.
Barber shop	15	In hotel.	In hotel.
Restaurant: Café	16	46 × 18 ft. and 33 × 36 ft. = 2 016 sq. ft.	2 016 sq. ft. and 16.9 × 79 ft. — 1 335 sq. ft., and 36.6 × 71.8 ft. — 2 628 sq. ft.
Lunch	17	58 × 42 ft. — 2 436 sq. ft.	58 × 42 ft. = 2 436 sq. ft.
Dining	18	75 × 65.5 × 15.75 = 4 912 sq. ft.	75 × 65.5 × 15.75 ft. = 4 912 sq. ft.
Kitchen	19	39 × 22 × 15.75 — 858 sq. ft. (dining). 18.6 × 24 × 16 = 446 sq. ft. (lunch).	39 × 22 × 15.75 ft. = 858 sq. ft. (dining). 18.6 × 24 × 16 ft. — 446 sq. ft. (lunch).
Pantry	20	27 × 42 × 15.75 = 1 152 sq. ft.	27 × 42 × 15.75 ft. = 1 152 sq. ft.
Store room	21	66 × 12.3 = 814 sq. ft.	66 × 12.3 = 814 sq. ft.
Carriage concourse	22	28 × 28.8 + 64 × 73 ft. = 5 474 sq. ft. inside. 88 × 71 ft. = 6 248 sq. ft. outside.	None inside. 88 × 71 ft. = 6 248 sq. ft. outside.
Ticket office	23	63 × 40 ft. = 2 520 sq. ft.	78 × 32 ft. = 2 496 sq. ft.

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TABLE 7.—COMPARISON OF FACILITIES AT ST. LOUIS UNION STATION, BEFORE AND AFTER RECONSTRUCTION (SEPTEMBER 30TH, 1904).

SPECIAL INFORMATION.

Items Compared.	Before Reconstruction.	After Reconstruction.
TRAIN-ROOM:		
Number of tracks	32	32
Scheduled trains per track:		
In 24 hours	7 (Jan. 11th, 1902.)	14.6 (July 15th, 1904.)
In busiest hour	1.16	1.5
SCHEDULED TRAINS:		
In 24 hours: Through	176	302
Suburban	48	48 suburban. 118 shuttle.
Total	224	468
In busiest hour: Through	31 (7 to 8 A.M.)	44 (7 to 8 A. M.)
Suburban	6	5
Total	37	49
TRAIN MOVEMENTS AT STATION, DAILY, OVER INTERLOCKING:		
In 24 hours:		
Loaded passenger	364	740
Empty passenger	(See switching.)	396
Light engines	736	792
Switching	573	188
Freight	162	87
Total	1 835	2 203
In busiest hour:		
Loaded passenger		50 (7 to 8 A. M.)
Empty passenger		35
Light engines		55
Switching		13
Freight		5
Total		158
WAITING-ROOM:		
Passengers per square foot:		
Maximum	5	7
Average	2 (in 24 hours.)	5
MIDWAY:		
Area	30 300 sq. ft.	42 420 sq. ft. permanent. 30 050 sq. ft. temporary.
Width	50 ft.	70 ft. and 50 ft.
Gates to trains: Number	17	17 17
Width	6 ft. 8 in.	7 ft. 9 in. and 6 ft. 8 in.
Total width	113 ft.	131 ft. and 113 ft.
Entrances to Midway: Number	31	31
Total width	210 ft.	210 ft.
Passengers in 24 hours:		
Per square foot area	1	2.5
Per foot of entrances	140	450
Passengers in busiest hour:		
Per 10 sq. ft. area	1.6	3.5
Per foot of entrance	25	75
Booths in Midway: Number	3	7
Area	260 sq. ft.	1 030 sq. ft.
Number of rooms opening on Midway.	10	12
PASSENGERS:		
Average number per scheduled train:		
In 24 hours	120	200
In busiest hour	160	275
On scheduled trains in 24 hours:		
Through	22 000	80 000
Suburban	8 000	20 000
Total	30 000	100 000
On scheduled trains in busiest hour:		
Through	3 800	12 000
Suburban	1 200	3 000
Total	5 000	15 000
Maximum number in 24 hours	75 000	150 000

Mr. Greensfelder.

TABLE 7.—(*Continued.*)

Items Compared.	Before Reconstruction.	After Reconstruction.
CARS:		
Cars per train carrying cars of such class:		
Mail	1.28	1.43
Express	1.17	1.37
Baggage	1.10	1.10
Combination	1.00	1.00
Passenger	1.87	2.89
Dining and Observation	1.13	1.00
Pullman	1.89	2.76
Total	4.66	5.44
Total number handled in 24 hours:		
Mail	75	100
Express	50	50
Baggage	125	250
Combination	(Included with baggage cars.)	(Included with baggage cars.)
Passenger	650	1 050 (shuttle, 250.)
Dining and Observation	25	50
Pullman	175	450
Total	1 100	2 200
Total handled in busiest hour:		
Mail	....	17
Express	....	9
Baggage	....	35
Combination	....	(Included with baggage cars.)
Passenger	....	138
Dining and Observation	....	2
Pullman	....	91
Total	....	292
TRAIN LENGTH:		
Average train length, including engine:		
Through	485 ft.	530 ft.
Suburban	240 ft.	315 ft.
Average	390 ft.	450 ft.
TICKETS:		
Ticket-selling space:		
Area	63 × 40 ft. = 2 490 sq. ft.	78 × 32 ft. = 2 496 sq. ft.
Linear feet of counter	100 ft.	220 ft.
Number of windows	22 + 2 Pullman.	41 (Pullman separate.)
Total tickets sold in 24 hours	2 365 in 1902.	5 345 in Sept., 1904.
TOILET ROOMS:		
Number of fixtures:		
Urinals	12	48
Closets	13	88
Basins	9	34
Private rooms	5 at 5 cents, 10 at 10 cents.	18 at 5 cents, 40 at 10 cents.
Passengers per fixture in 24 hours:		
Urinals	2 500	2 000
Closets	2 300	1 100
Basins	3 300	3 000
Private rooms	6 000 at 5 cents, 3 000 at 10 cents.	5 000 at 5 cents, 2 500 at 10 cents.
BOOTHS:		
Number of telephones	2	8
Parcel-rooms:		
Total area	516 sq. ft.	4 060 sq. ft.
Number of rooms	1	4
Shelving	785 lin. ft.	6 400 lin. ft.
Parcels in 24 hours	750	5 800
News:		
Total area	....	530 sq. ft.
Number of rooms	3	3
Flower area	100 sq. ft.	....
Candy area	638 sq. ft.	428 sq. ft.
Cigar area	....	425 sq. ft.
Number of rooms	3	3

Mr. Greensfelder.

TABLE 7.—(*Continued.*)

Items Compared.	Before Reconstruction.	After Reconstruction.
RESTAURANTS:		
Seating capacity per room:		
Lunch	42	42
Dining	275	275
Café	114	344
Passengers in 24 hours, per seat:		
Lunch	700	2 200
Dining	100	350
Café	200	300
CAB STAND:		
Area	5 474 sq. ft. inside. 6 248 " " outside.	0 inside. 6 248 sq. ft. outside.
Platforms	90 lin. ft.	130 lin. ft.
BAGGAGE:		
Pieces handled in 24 hours:		
Average	3 675 in 1902.	9 500 in September, 1904.
Maximum	....	13 700 in September, 1904.
Pieces per train	16	20
Passengers per piece	8	10
Area per piece	5 sq. ft.	5.5 sq. ft.
Pieces per linear foot of counter	75	100
TRACKS:		
Number of train-shed tracks	32	32
Number of approach tracks	4	6
Approach tracks per shed track	1 in 8	1 in 5.3
Main tracks	3	7
Mileage of shed tracks	3.5	6.5
Mileage of approach tracks	5.5	11
YARDS:		
Number of yards	2	5
Total yard area	20 acres.	40 acres.
Total yard mileage	10	21.5
Total yard capacity	300 cars.	625 cars.
INTERLOCKING:		
Area covered	17 acres.	30 acres.
Track mileage	9	17.5
Number of towers	1	3
Total number of levers	131	321
Total number of working levers	101	260
Number of levers in largest machine	131	215
Switches operated	61	90
Double slips operated (M. P. F.)	12	67
Signals operated	105	284
Total lever movements in 24 hours	25 000	....
Average lever movements per train movement	13.6	....
Average lever movements per scheduled train	11	....
POWER-HOUSE:		
Steam	1 500 h. p.	2 750 h. p.
Electricity	655 kw.	1 530 kw.
Compressed air	3 575 cu. ft. free air per min.	4 450 cu. ft. free air per min.
Hydraulic power	None.	150 h. p.
COALING STATION:		
Coal capacity	100 tons.	1 000 tons.
Engines handled in 24 hours	60	100
ENGINE-HOUSES:		
Number of houses	1	3
Engines in 24 hours	3	60

NOTE.—Old train record taken January 11th, 1902.
New " " " July 15th, 1904.
The number of passengers is from estimate only.

Mr. Greensfelder. of the floor opening in front of this stairway has been bridged, and all the seats have been moved from the first-floor waiting-room to this place. The waiting passengers now use this hall almost entirely, and, as desired, keep the room below clear for passengers desiring to use the ticket-office, bureau of information, parcel-rooms and restaurant.

Mr. Woodard. Wilkie Woodard, Assoc. M. Am. Soc. C. E., Cincinnati, Ohio.—The speaker would like to know the minimum width for a passenger platform for a railway station, and also the degree of curvature to be used in approaches to union stations. In some cases, it is worth spending a large amount of money to reduce the curvature. One station in London has something like a 14° curve, which is about the heaviest that can be obtained. It would seem that an 8° curve would be about right.

Some of the stations, according to Mr. Corthell's paper, have 2 and 2½% grades, and others have none. Is a 1% grade objectionable?

Mr. Parsons. George W. Parsons, Assoc. Am. Soc. C. E., Steelton, Pa.—The speaker would commend for adoption in the United States, the European custom regarding station signs. In this country, many important stations are destitute of any sign denoting the name of the station, and in other cases the signs are too small, even for people with fairly good sight, and too few. In Europe, generally, the stations have several signs, in large letters, well placed for the information of the traveler, who is, therefore, not wholly dependent on oral announcements.

Mr. Tratman. E. E. R. Tratman, Assoc. M. Am. Soc. C. E., Chicago, Ill.—When the subject was first announced, the speaker hoped that the papers would deal with the principles involved in the design of stations and terminals, but it appears that this was not intended to be the scope of the papers, which are mainly descriptive of individual terminals. The Yards and Terminals Committee of the American Railway Engineering and Maintenance-of-Way Association has been working for the past three or four years trying to define and lay down certain general principles or considerations which would govern, in nearly all cases, independent of local conditions. The work, so far, has been mainly in regard to freight terminals, and it has been difficult to arrive at anything definite, but the Committee has developed certain conclusions which should be followed in any general design. Of course this cannot be done in regard to dimensions and details; these must always depend upon what ground is available (both as to size and shape), and upon the character of local facilities to be provided.

At large freight terminals, economy in space can often be obtained by the use of freight houses, two or more stories high, the

Mr. Tratman. cars being handled by elevators. Mr. Foxlee describes the Deansgate Freight Station at Manchester, where the second floor is accessible from a viaduct, while inclines serve the first floor or street level. This arrangement is, of course, exceptional and rarely possible, but elevators can be used in any case. In this connection, it may be appropriate to refer to the advisability of removing large switching yards from the expensive land which they sometimes occupy in large cities. At Chicago, the Chicago Transfer and Clearing Company has established extensive yards in the outskirts of the city, with the intention of inducing the railways entering the city (20 or more) to use this as a "clearing house," instead of each road operating a transfer service with all the other roads. Freight trains of all roads would be run directly to this point, where through cars (representing 60 to 65% of the total) would be sorted out and delivered to the various roads over which they are to proceed. Then only the cars destined for Chicago would enter the city yards of the individual railways, thus greatly reducing the amount of switching and transfer service on the part of these railways, and enabling large tracts of land in the city to be used for more profitable purposes.

In the design of joint or union passenger stations, it is often a question as to how far it is advisable to concentrate or centralize traffic. In St. Louis, the one great station serves some 18 railways. In Chicago, with its six terminal passenger stations for 24 railways, elaborate plans were prepared some time ago for a proposed union station to take the place of all others. But the existing stations are so well established, that no such change is probable, and the general opinion is that such a centralization would not be satisfactory. On this point, it may be noted that Chicago has a very much heavier suburban traffic than St. Louis. On the other hand, the eight terminal stations in Boston have given place to two large modern stations. This matter has come up in various other large cities, including London, England, with its great railway traffic. Another aspect of the case is the provision of special transportation facilities for connecting the various stations in a large city, but this would almost always be taken up as a part of a system of local transportation. An important matter in regard to passenger terminals is the location of the car-cleaning and storage yards, enginehouses, water and coaling stations, etc., as upon the proper relation of these various facilities to one another depends very largely the convenience, efficiency and economy of operating the station and the terminal plant as a whole.

Another important point mentioned in Mr. Foxlee's paper is in regard to the avoidance of grade crossings at junctions and entrances to freight yards. In many cases in Europe where the traffic is heavy, the diverging line (either for a branch or a yard connection) is diverted and carried over under the main tracks, so as to avoid the danger or delay due to trains crossing or fouling the main tracks. The additional expense is well warranted by the increased safety and facility of operation of the traffic. The Pennsylvania Railway has an arrangement of this kind near Philadelphia, and the New York, New Haven and Hartford Railway has another example near New York. Mr. Tratman.

The handling of baggage at large stations is a difficult proposition, and the successful application of mechanical conveyors to this work, as in Paris, is a feature worthy of careful consideration. The system of transferring baggage checks by pneumatic carriers between the checking counter and the baggage-room, as adopted at the St. Louis Station, is also of interest in the same connection. The American system of checking baggage is excellent, but the weak point of the baggage department is the reckless way in which the baggage is thrown about. Many foreign visitors have expressed surprise at this, and foreign railways certainly have the reputation of handling baggage with greater care. It is very desirable that better discipline should be exercised in regard to this, but the matter appears to receive very little attention.

In Mr. Pontzen's paper, there is reference to the co-operation of city and railway authorities in the design of terminal facilities at large ports. In too many cases, these authorities antagonize one another, with results that are, naturally enough, unsatisfactory to both parties as well as to all those who have occasion to make use of the facilities. Wherever they will act in co-operation, the interests of all parties concerned may be served to advantage.

S. G. Homfray, M. Inst. C. E., London, England.—The speaker's interests are more particularly with appliances used in terminal and other stations, in regard to which the site and the circumstances are the governing factors, to meet which the necessary appliances can be practically always devised. Double-deck freight stations have been mentioned, and the speaker would like to say that, in England, double-deck freight stations have been used for a great many years, this being especially the case in London and other large cities. In some cases, the rail traffic comes in and goes out on the upper level, and, in other cases, on the lower level. In either case, it is common to work the traffic on two decks, the transfer of wagons from one deck to the other being effected by hydraulic lifts taking one wagon at a time, there generally being access for road carts and vans at both levels. In many cases, there are also several floors above the upper railway tracks which are used for goods, and equipped with hydraulic cranes and lifts. The speaker's firm, Sir W. G. Armstrong, Whitworth and Company, Limited, is making a Mr. Homfray.

Mr. Homfray. hydraulic lift for a double-deck freight station in South Africa for dealing with bogie cars having a gross weight of 50 tons, the rail gauge being 3 ft. 6 in.

For passenger stations, great attention is directed to the question of dealing with the parcels and luggage traffic without encumbering the platforms, and, in new stations, this is generally done by either underground passages or overhead bridges, the communication with the platform, in either case, being by lift.

Mr. Camp. W. M. Camp, M. Am. Soc. C. E., Chicago, Ill.—Mr. Foxlee, in his conclusions, states that roofs of small span, varying from 50 to 75 ft., are the most economical to construct and maintain. In some parts of the United States, it has been found desirable, at least, to go even farther than Mr. Foxlee recommends, and construct separate roofs over the platforms, between the tracks, as substitutes for a train-shed. Such construction, known as "umbrella" roofs, has been growing in favor in this country during the past ten years. A good example is to be found at the passenger station of the Texas and Pacific Railway, at Fort Worth, Tex., built about four years ago. At that station there are six stub-end tracks, in three pairs, running up to the station building, and, between each two pairs, and on the outside of all the tracks, there is a shed of steel construction extending 608 ft. from the station.

While it is usually considered that the umbrella type of shed is permissible only in southern climates, the speaker thinks that, all things considered, the comfort of the passenger would be better provided for by a greater use of them in the North also. To cite an example of such construction at a northern point, the Burlington and Missouri River Railroad Station, at Omaha, Nebr., built six years ago, is provided with this type of shed. On many roads, the sides of train-sheds are left open to improve the ventilation and alleviate somewhat the conditions which are found under large roofs where locomotives must stand with steam up.

The usual design of platform roof is pitched outward, or slopes toward the track. This makes eaves-troughs necessary to prevent dripping of water at the sides of the cars. In order to avoid this, the roof may be pitched toward the center of the platform, into a valley which is drained with down-spouts at the center line of the shed. It will be noticed that the design shown in Mr. Corthell's paper, as adopted for the new Union Terminal Station at Washington, overlaps the roofs of the cars about 18 in. While this type of roof is not new, it has not as yet come into extensive use.

Mr. Moore. Robert Moore, Past-President, Am. Soc. C. E., St. Louis, Mo.—A matter worthy of careful consideration in planning a passenger station is whether, in this climate at least, it is not best to do away with the large shed covering the tracks and platforms, and replace

Mr. Moore.

it with umbrella sheds covering the platforms only. The large shed is not only very expensive to build and to maintain, but it has the further great disadvantage of keeping in the smoke and keeping out the light and air. The umbrella shed, on the other hand, abates the smoke nuisance entirely, and, except in the rare event of a driving storm, gives all the protection needed in passing to and from the train. Examples of the satisfactory working of umbrella sheds are found in the Union Station at Kansas City and in those of the Union Pacific and Burlington Systems at Omaha—all large and busy stations. And further confirmation of this view is found in the fact that in the Union Station at Washington, now in progress and on which no expense is to be spared, there will be sheds over the platforms only, the tracks being left uncovered.

Mr. Morgan.

CHARLES L. MORGAN, M. INST. C. E., London, England. (By letter.)—Mr. Foxlee's paper is interesting as giving a record of the most modern English terminals. By comparing the various plans, it brings out very fully the fact that no standard design can be usefully laid down for a terminal station in Great Britain, and it is evident that the accommodation provided in the terminals must be governed by their geographical position and surroundings, and, with this fact admitted, with due regard to the special nature of the traffic to be dealt with, it rests with the engineer to make the best possible use of the space at his disposal.

It will be seen from the drawings the great diversity there is, both in plan and in the amount of accommodation provided for in various terminals, and also the absence of any fixed ratio of platform and approach accommodation, in relation to the number of trains or the number of passengers using the terminals.

In designing a terminal station, one great feature to be borne in mind is that the platform accommodation should be sensibly in excess of the greatest number of trains which can be run into the stations over the approach lines. Generally speaking, all terminals have suffered more or less, in the past, from the accommodation in this respect being the reverse of the proposition laid down, with the result that, at busy times, confusion has reigned more or less, and unpunctuality has of necessity arisen.

In laying out the plan for the enlargement and reconstruction of Victoria Station, the geographical position was a difficult one, as, on one side, extension was next to impossible, the Brighton Company's Railway and Station at this point being bounded by that of the South Eastern and Chatham Company, and, on the other side, for the greater portion of its length, by the public highway, Buckingham Palace Road. It was, therefore, only possible to get a very small enlargement in width, some 50 ft. altogether, *viz.*, on the Buckingham Palace Road side, and, therefore, the writer was driven

Mr. Morgan. to the expedient of getting the additional accommodation by an elongation of the station. In this feature, the station is unique, and a departure from the ordinary and better practice of forming out and obtaining extra platforms, each to accommodate a single train, wherever possible. As this was impossible, the scheme he devised, and is carrying out, provides for each platform to accommodate two trains.

The station may, for the purposes of discussion, be treated as two separate stations, *viz.*, "inner" and "outer," the former being the portion between the booking office and Eccleston Bridge, and the latter the portion lying between the Eccleston and Elizabeth Bridges.

As to the general accommodation, the plan speaks for itself, but it may be well to point out how the working of the station is intended to be carried out, so as to avoid, as far as possible, any material inconvenience, owing to the extreme length of the platforms.

It will be found almost invariably that, in existing terminals, in all platforms of sufficient length to take two trains, the first train to arrive must of necessity be the last to depart, as the last train in must first clear from the other end of the platform. This is a serious objection in actual practice, and leads to a limitation of working between the platforms.

It will be observed that there are three lines of way in the "outer" station, and it is hoped that the third or middle road will give such facilities of working, as will entirely avoid the objection to double-length platforms, as previously pointed out.

The working proposed is that the first train to arrive will discharge in the "inner" station, and be followed by a light engine from one of the engine roads, coupled to the rear of the train, and taken on its next ground. Immediately the first train has come to a stand, a second train will be received into the same platform line in the "outer" station, and whilst this is discharging, the train which arrived first in the "inner" station will be loading, and will pass through the middle road, before referred to, followed by the engine which first brought it in.

The second train which arrived in the "outer" station and has discharged will then draw forward and load from the "inner" station, so that passengers departing will not, except under exceptional circumstances, have to walk to the "outer" station for a departure train, although, during the very heavy press of excursion and holiday traffic, it may be that they will, in some cases, have to do so. At the slack times of the day and night, the outer station will practically not be used at all.

The approach lines to the station are four in number, and the platform accommodation being well in advance of the feeding capacity of these lines, the result will be to enable all the main-line trains to take up their positions in the departure platforms some considerable time before they are due to leave, when the luggage, etc., can be loaded as, and when, the passengers arrive at the station, and thus avoid what now takes place, owing to the limited platform accommodation, the train being put into position only a few minutes before the advertised time of departure, and inevitable delay being incurred, to say nothing of confusion and discomfort of the passengers. **Mr. Morgan.**

It is hoped, therefore, that the enlargement of the station, on the lines shown upon the plan, which does not look very inviting, will, in fact, prove a very convenient working station, both from the point of view of the company and the public using their railway.

Mr. Corthell. ELMER L. CORTHELL, M. AM. SOC. C. E., New York City. (By letter.)—It having been the writer's lot to travel considerably in various countries, he has noted the handling of baggage, and has found it a problem that needs consideration. It would be very convenient if, in all large cities, baggage could be checked to its destination from the hotel, and also from private houses. This is done already, in some cities, but it is the usual practice, even in London and Paris, to send for a "four-wheeler"—a very small carriage—to take one to the railway station. All one's baggage, both large and small pieces, is placed on top, with the overflow inside, and at the station the passengers and baggage are usually dumped out in a small place, where it is very inconvenient to handle the baggage. The Liverpool Street Station, in London, may be instanced, where one morning the writer and about twenty other passengers, with their baggage, were deposited all together in a small room, and this was at a station where it was not uncommon to handle 200 000 passengers in one day.

In reference to the improvements for handling baggage in stations, it might be mentioned that the plans described in the writer's paper, as in use at the Western Railroad in Paris, where the baggage is handled mechanically, have been greatly improved at the new Station Quai d'Orsay, in Paris, described by Mr. Pontzen.

In reference to the platforms, European stations are generally in advance of stations in the United States, as they are usually much wider and more solid, being built of concrete. In Europe, also, a platform is rarely used at the same time by two trains. Mr. Foxlee has stated that the platforms which he has designed for the Waterloo Station are about 30 ft. wide.

In respect to subways under the tracks, there are better facilities in Europe than in the United States, as such subways are more numerous, and they are generally arranged as in the Frankfort Station, so that a passenger can use a subway to pass from a train entering the station to a train departing, and by this means often

Mr. Corthell. make connections, which could not be done if he had to go to the front of the station and out to the other train at another platform. The writer recently found this arrangement to be of great advantage at the Frankfort Station when he had about half a minute in which to make connection between arriving and departing trains.

The writer thinks that in Europe, generally, more information is given to passengers by means of signs, and plenty of them, than in the United States.

Engineers in the United States should devote more study to the problem of handling express and postal matter, and baggage by means of subway and lifts. This method is now in use at the Union Station in St. Louis, and at the South Union Station in Boston. The latter is a model station, where everything is handled quickly, and the people know where to find their trains.

The writer has been informed by Mr. Greensfelder that in the new plan of the St. Louis Station all trains are backed in, and go out head-on. Also, that the square diagram outside the station, near the interlocking tower, is a signal bridge in front of the tower, and that the bridge governs four directions and is really four signal bridges, and, further, that the four bridges do not obstruct the view of the operator, as the signal bridges are just above his eye.

In reference to the question asked by Mr. Woodard, the writer thinks that the width of platforms to be used at railway stations should be not less than 15 ft., and from that up to 30 ft.

As to the degree of curvature used in the approaches to union stations, Mr. Woodard is correct in stating that the curvature should not exceed 8°, certainly it should not exceed 10° in entering a station, but sometimes it is absolutely necessary to have sharper curves, on account of valuable property or the position of the station in reference to fixed and immovable obstacles.

The writer is of the opinion that a descending 1% grade, entering a station, is not objectionable, but is not good practice. The Grand Central Station, New York, has a descending grade of $\frac{35}{100}$ of 1% entering the station. A slight descending grade is not dangerous, and is certainly very convenient in running trains to other tracks by a flying switch, as is done at the Grand Central Station.

The difference in the cost of doing business in end-on and through stations is interesting. The average cost per car in the St. Louis Station is given in the writer's paper as $1.58; in the Indianapolis Station, which is a through station, it is given as $0.55, or about one-third as much. The writer cannot explain fully the causes of this difference. The costs are stated as given to him by the railroad companies, but he thinks that the cost of maintenance and operation for a station like that at St. Louis is much greater than for one like that at Indianapolis, where the train-shed is attached to the head-house. There is not as much expense in handling **Mr. Corthell.** trains passing directly through a train-shed, open at both ends, as in the case of the St. Louis Station.

In reviewing the discussion, the writer desires to express his satisfaction in that his paper has been received with appreciation.

An attempt was made to give facts, not views, and these facts had been obtained by several years of examination of stations, by correspondence, and by study of the data. If those facts, as collated, should prove to be of value to others, his labor has been well spent.

It was difficult to keep the data up to date, for while obtaining and compiling them, in the course of some years, he had often been apprised of the fact that reconstructions, enlargements, and particularly increase in traffic, had changed the figures and made the first data antiquated. This is exemplified in the very valuable discussion of Mr. Greensfelder by his comparison of the various features of the St. Louis Union Station before and after reconstruction, the time intervening being about 2½ years.

The writer desires to call attention to an error in Mr. Tratman's discussion, where he states that "In St. Louis, the one great station serves some 18 railways." The number was 21 at the time the writer obtained his data, and later, according to Mr. Greensfelder (Table 6), it was 23.

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OF THE

American Society of Civil Engineers.

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ERRATA.

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TRANSACTIONS.

Vol. LIV, Part B.

Page 81, line 5: For “3-panel” read “triple.”

Page 83, line 34: For “8-panel” read “octuple.”

Page 83, line 38: For “flash, 4 sec.” read “flash, 0.1 sec.”

Page 85, line 8: For “680” read “480.”

Page 391, foot-note: For “Chief Mech. Engrs.” read “Chief Mech. Engr.”

Page 478, Table 2, Column 7: Strike out decimal points.

Page 513, line 9: For “1855” read “1918.”

Vol. LIV, Part C.

Page VI, line 14: “For “M. O’Shaughnessy” read “M. M. O’Shaughnessy.”

Page VI, line 32: For “N. Daymard” read “V. Daymard.”

Page 368, line 15: For “describe” read “escribed.”

Page 481, lines 10 and 20: For “409” read “407.”

Page 482, line 24: For “452” read “450.”

Page 496, line 28: For “406” read “404.”

Page 499, line 29: For “441” read “439.”

Page 499, line 42: For “407” read “405.”

Page 499, line 43: For “420” read “418.”

Page 500, line 35: For “407” and “408” read “405” and “406.”

Page 513, line 34: For “456” read “454.”

Page 516, line 31: For “418” read “416.”

Page 516, line 32: For “418 to 434” read “416 to 432.”

Page 517, line 24: For “428” read “426.”

Page 519, line 14: For “448” read “446.”

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Page 348, line 12: Insert side note “Mr. Henderson.”

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PREFACE TO VOLUME ONE

THIS book is the written word of many years of lecturing in Glasgow University. As these lectures have never been written as they were delivered, and as new matter was necessarily added to the lectures as it became available, the chapters of this book do not represent any one systematic series of lectures, though there is little in the book but what has been given at some time to the students. The process of writing such a book is very dissimilar to that of writing most books. Much of it at first was collected from lecture notes by one or other of my assistants. These collections were elaborated, modified, rewritten in parts, and finally corrected in the form in which they now appear. In the collecting and correcting process I was continually helped by my assistants and students, but the bulk of the assistance was given me by Mr. J. G. Johnstone, B.Sc., to whom I am indebted for saving me a great deal of detail work in the collection of what I have given from time to time in my lectures. Some of the calculations were made by students of the Naval Architecture Class.

This book cannot possibly lay any large claim to originality. The greater part is necessarily the work of others who went before or who are now working for the advancement of the science of Naval Architecture. Very little attempt has been made to acknowledge the sources of such help. The subject is too wide to attempt to acknowledge all the sources, even if one were qualified to do so. But there are parts which are original work given for the first time in the lecture-room, though some has been already published, mostly in the *Transactions of the Institution of Naval Architects.*

The subject is developing year by year, and often so rapidly as to make it very difficult, if not almost impossible, to read all that is published on the subject. There are further stores of knowledge which are never published, and are only accessible to individuals associated with the ship-building establishments, in which much expense is incurred in investigations and experiments for the advancement of knowledge of the subject. To many such I have been indebted from time to time for the ready reply to requests for information.

This book is primarily intended for young students, but it is hoped that many who have been students, and some who in their daily work are interested in the problems dealt with, may find some assistance. There must be some errors and shortcomings in such an attempt; but it is sincerely hoped that, in spite of these, the work may serve the purpose of assisting some to a better knowledge of the science of Naval Architecture.

JOHN HARVARD BILES

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The Engineering News Says:—

"The author of this work has been for nearly twenty years Professor of Naval Architecture at the University of Glasgow—the first British university to establish a course in Naval Architecture. Before the present excellent courses were established by several universities in this country, a large proportion of the government and private students going abroad for the study of Naval Architecture went to the University of Glasgow, and Professor Biles has a number of former students in this country.

"While Professor Biles went to the University of Glasgow as a comparatively young man, it was after a wide professional experience—he was manager at Thomson's when that firm built the 'Paris' and 'New York.' Since going to the University of Glasgow, he has by no means restricted his energies to the teaching of Naval Architecture, but has done much active work of a consulting nature and been a nember of several important government commissions."

the readings for moment of inertia to such a scale as will make the final ordinates equal. This has been done in diagram, fig. 209. The curve for moment of inertia is F I C. It can be easily proved that the difference between the ordinates of the curves F I C and F M C (fig. 209) at any section gives *m*. This difference has been plotted on a straight base to a standardised scale.

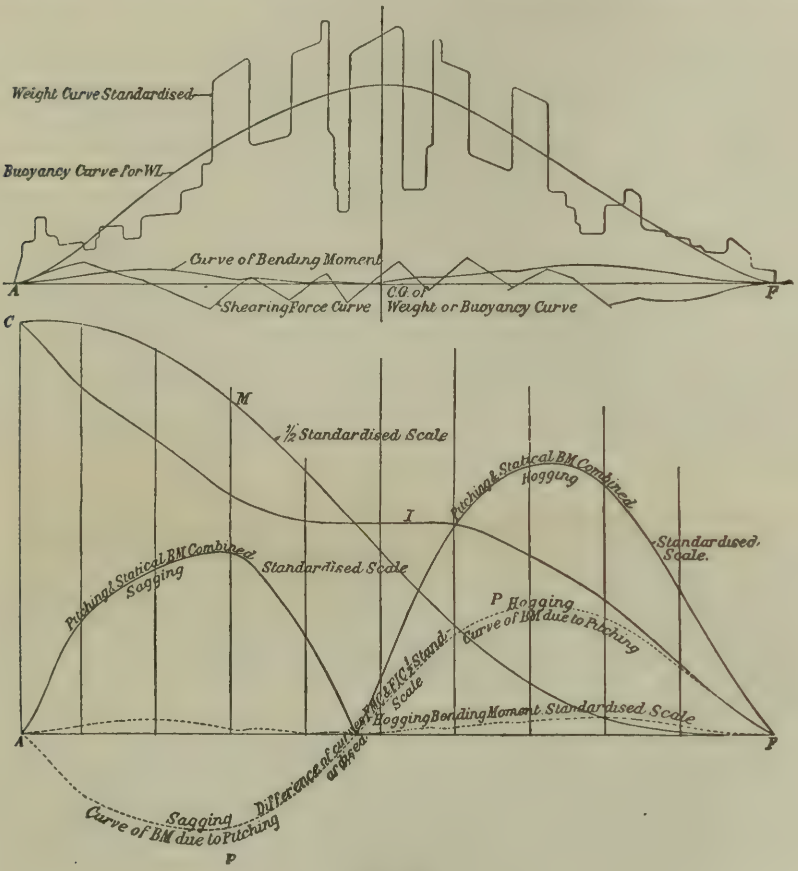
Weight Curve Standardised
Buoyancy Curve for WL
Curve of Bending Moment
A
F
Shearing Force Curve
C.G. of Weight or Buoyancy Curve
C
M
½ Standardised Scale
I
Pitching & Statical BM Combined Hogging
Standardised Scale.
Pitching & Statical BM Combined Sagging
Standardised Scale
P Hogging
Curve of BM due to Pitching
FMC & FIC ½ Stand: Scale
Hogging Bending Moment Standardised Scale
A
F
Difference of curves as used
Sagging
Curve of BM due to Pitching
P

FIG. 209.

Results.

Maximum Hogging Bending Moment . . = 3230 ft. tons.
,, ,, ,, ,, from F. P. = 29 per cent. of L
,, Sagging ,, ,, . . = 2165 ft. tons.
,, ,, ,, ,, from A. P. = 27 per cent. of L.

The curve F P P A gives the bending moment due to pitching. The forward part of this curve is a hogging moment and the after part is sagging. This moment due to pitching at any section has now to be added or subtracted to the statical moment at the section in the still-water condition W L.

> " These bulkheads are to extend to the height of the upper deck in " vessels with one, two, or three decks, to the spar deck in spar-deck " vessels, and to the main deck in awning- or shelter-deck vessels.
>
> " In sailing vessels the foremost or collision bulkhead only will be " required."

It is evident that for equal safety in ships there should be equal division; in fact, smaller ships should have rather more subdivision than large ones, as the damage caused by collision is likely to extend to more compartments in the former. Hence length as a determining factor in the number of bulkheads cannot be chosen for purposes of safety. The number of bulkheads in a merchant ship is determined generally by practical considerations as to shortness of holds permissible for carrying cargo. The larger ships are much safer than the smaller, which is what they should be when their value is taken account of.

In large passenger merchant steamers it is usual to further subdivide the hull. The greater the size of the vessel, the greater the number the hatches must be in order that the cargo may be discharged or loaded at a satisfactory rate. This permits of correspondingly increased subdivision. In some cases the engine-room of twin-screw vessels is divided by a longitudinal watertight bulkhead. In high-powered ships additional transverse bulkheads are fitted in the boiler spaces.

In order to determine the number of watertight bulkheads that a vessel (for safety) should have, the effect on the draught, stability, and trim due to flooding the compartments has to be calculated.

One condition, for instance, may be specified, viz. that the vessel has to be subdivided so that she is able to keep afloat with any two adjacent compartments flooded. An arrangement of bulkheads can be approximately decided upon, and the position of the waterplane for each separate flooded condition can be calculated. It will then be seen if any of these conditions are dangerous, and the compartments may then be changed until the spacing of the bulkheads is satisfactory. This, however, is rather a laborious method of arriving at the required result. It is therefore necessary to make a more general solution of the question.

It is evident that, with any one length of compartment (*i.e.* any one spacing of transverse watertight bulkheads), for a given condition of ship there will be one definite change of draught, trim, and transverse stability, due to the flooding of this one compartment, for one position of the bulkheads.

A variation in the longitudinal position of the compartment will cause a variation in the above changes of draught, trim, and transverse stability. A variation in the length of the compartment will also cause a variation in these items. Hence we may find the value of the changes, first, for constant length of compartment and varying longitudinal position. We may then find the changes due to another, but different, constant length and varying longitudinal position, and so on, so that we may cover the whole of the possible ground of variation of length and position of compartment. When we fully know the effect of all these variations, we may then determine which of them causes the changes of trim, draught, or stability to be of a dangerous character. Such a general flooding calculation is usually made for the vessel, and the results are given in curves which show, in terms of the percentage of length of the ship assumed to be flooded, the actual changes of trim, draught, and stability. If upon these curves the permissible limiting values of these changes be drawn,

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